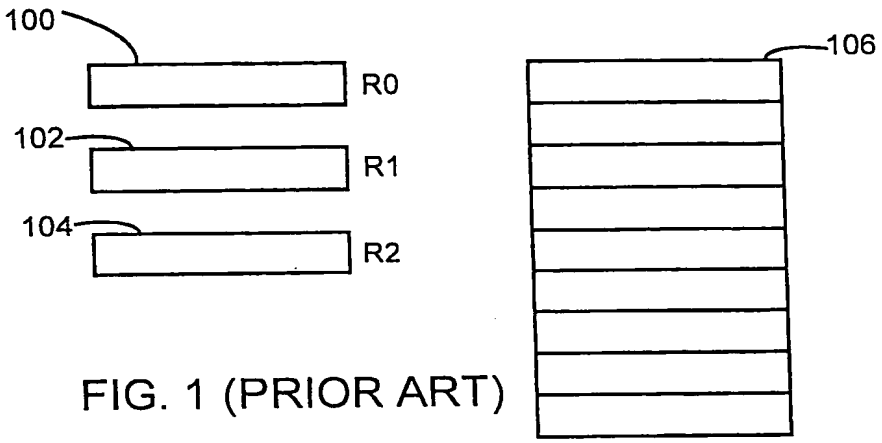


FIG. 1 (PRIOR ART)

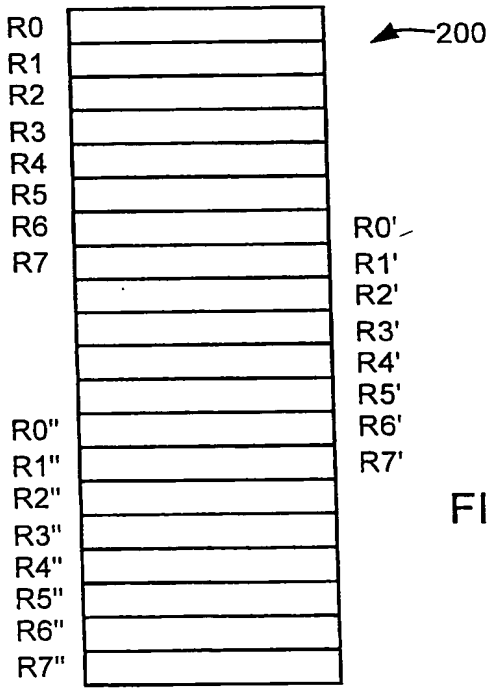


FIG. 2 (PRIOR ART)

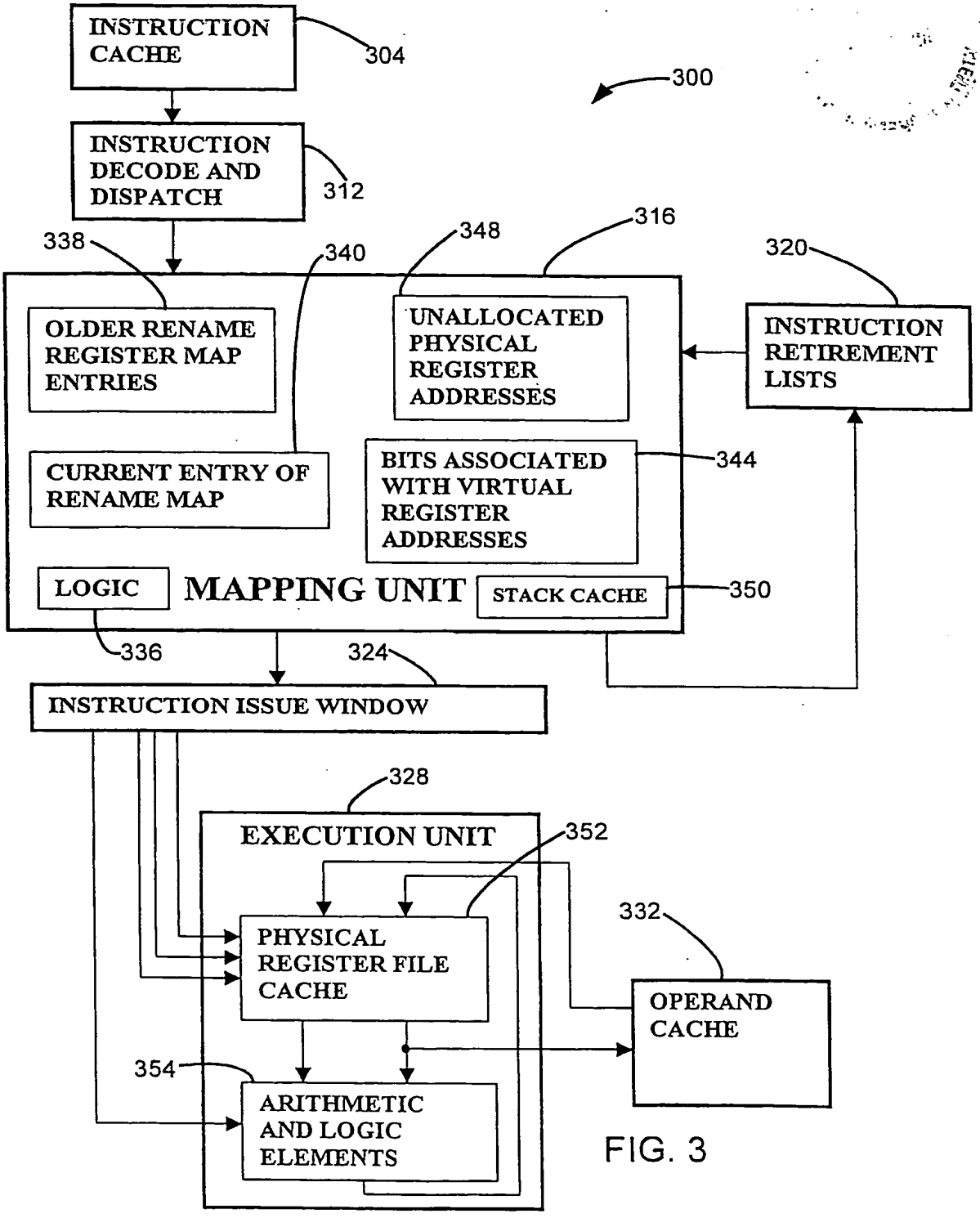

INSTRUCTION CACHE
304
300
INSTRUCTION DECODE AND DISPATCH
312
338
340
348
316
320
OLDER RENAME REGISTER MAP ENTRIES
UNALLOCATED PHYSICAL REGISTER ADDRESSES
INSTRUCTION RETIREMENT LISTS
CURRENT ENTRY OF RENAME MAP
BITS ASSOCIATED WITH VIRTUAL REGISTER ADDRESSES
344
LOGIC
MAPPING UNIT
STACK CACHE
350
336
324
INSTRUCTION ISSUE WINDOW
328
EXECUTION UNIT
352
332
PHYSICAL REGISTER FILE CACHE
OPERAND CACHE
354
ARITHMETIC AND LOGIC ELEMENTS

FIG. 3

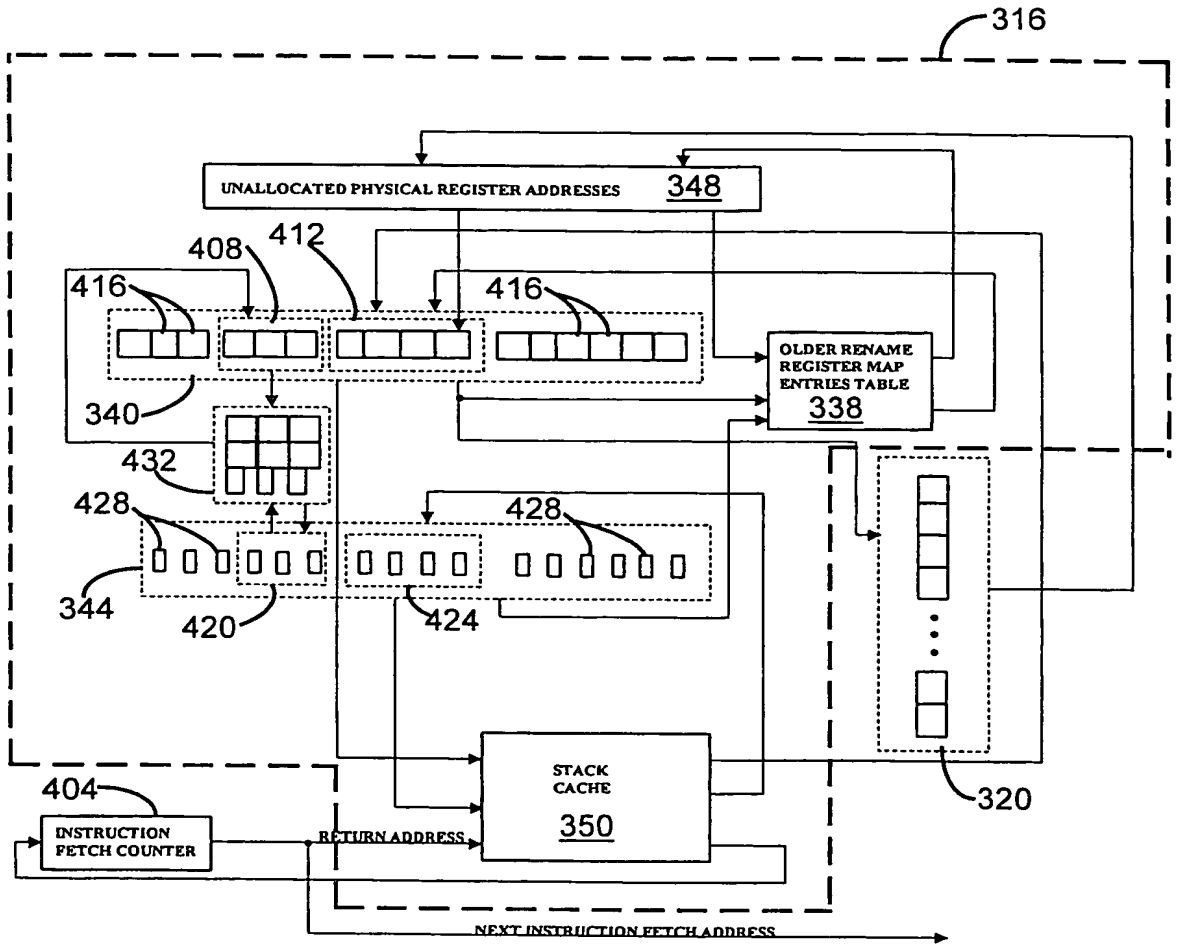

316
UNALLOCATED PHYSICAL REGISTER ADDRESSES
348
408
412
416
416
340
OLDER RENAME REGISTER MAP ENTRIES TABLE
338
432
428
428
344
420
424
320
STACK CACHE
350
404
INSTRUCTION FETCH COUNTER
RETURN ADDRESS
NEXT INSTRUCTION FETCH ADDRESS

FIG. 4

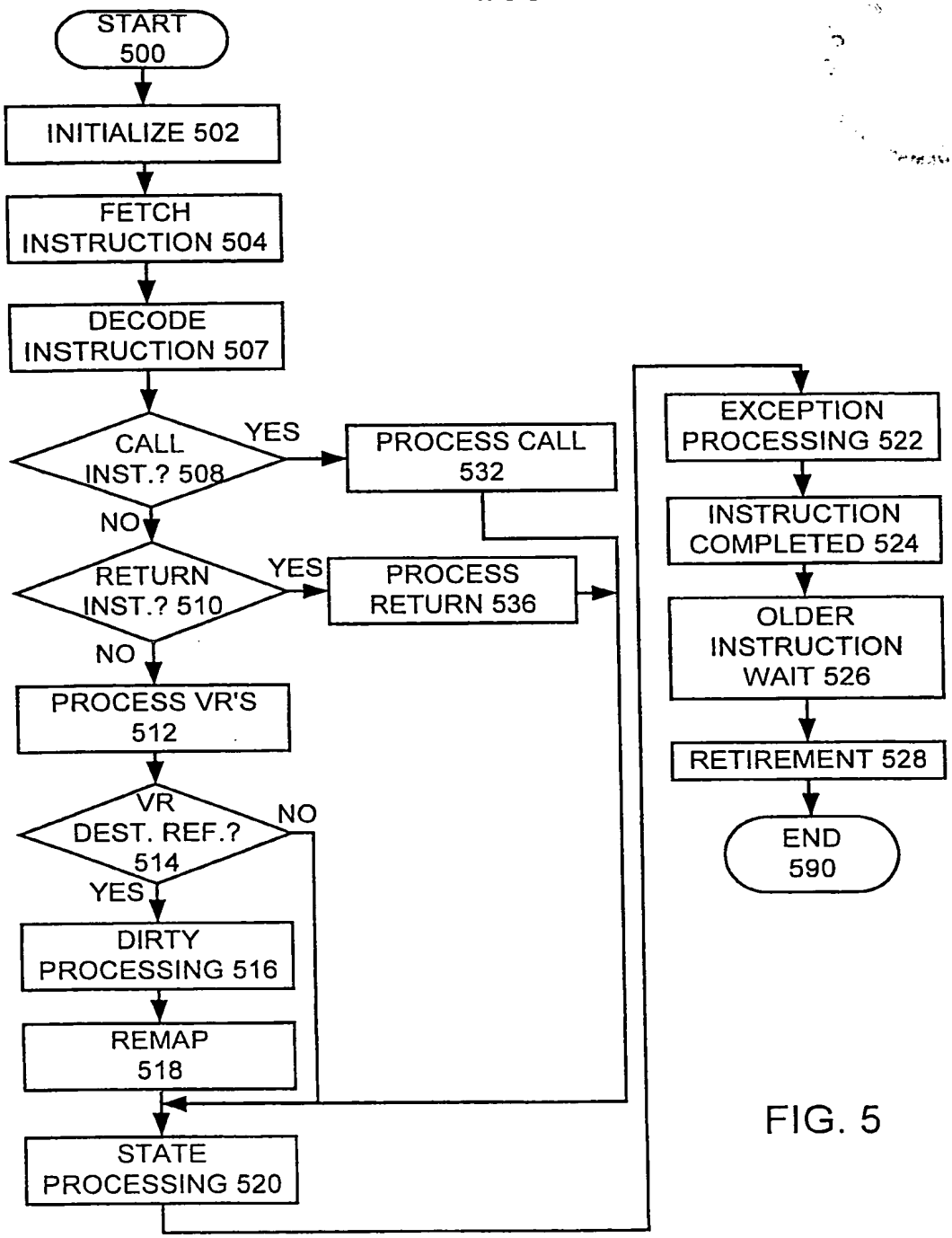

START 500
INITIALIZE 502
FETCH INSTRUCTION 504
DECODE INSTRUCTION 507
CALL INST.? 508
YES
PROCESS CALL 532
NO
RETURN INST.? 510
YES
PROCESS RETURN 536
NO
PROCESS VR'S 512
VR DEST. REF.? 514
NO
YES
DIRTY PROCESSING 516
REMAP 518
STATE PROCESSING 520
EXCEPTION PROCESSING 522
INSTRUCTION COMPLETED 524
OLDER INSTRUCTION WAIT 526
RETIREMENT 528
END 590

FIG. 5

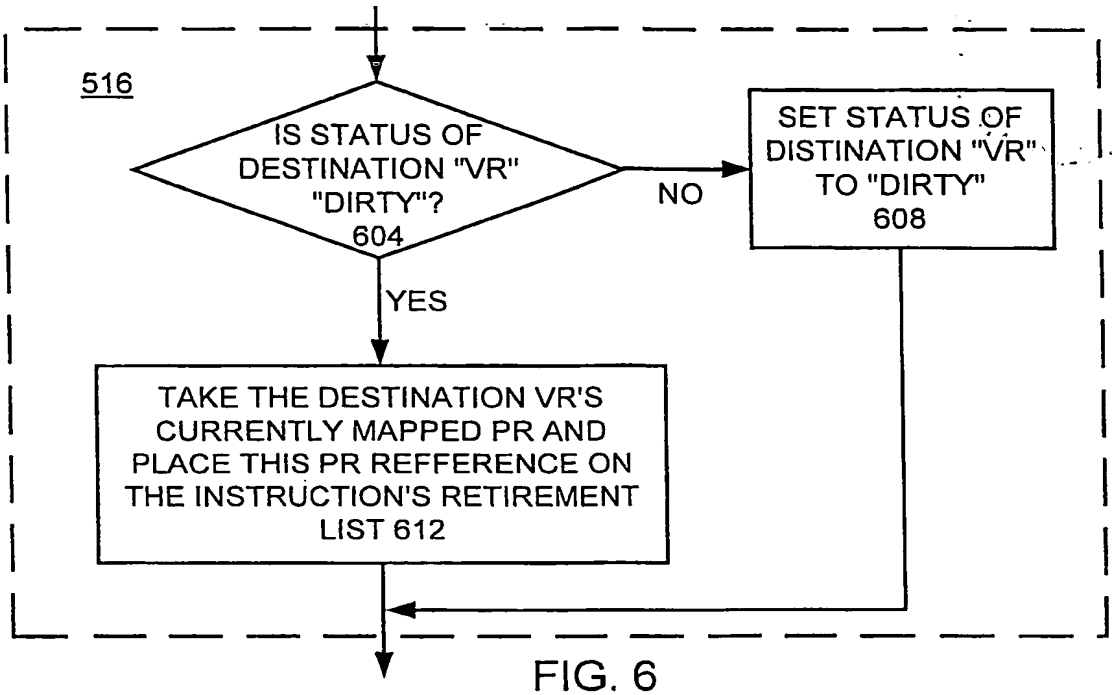

516
IS STATUS OF DESTINATION "VR" "DIRTY"? 604
NO
SET STATUS OF DISTINATION "VR" TO "DIRTY" 608
YES
TAKE THE DESTINATION VR'S CURRENTLY MAPPED PR AND PLACE THIS PR REFFERENCE ON THE INSTRUCTION'S RETIREMENT LIST 612

FIG. 6

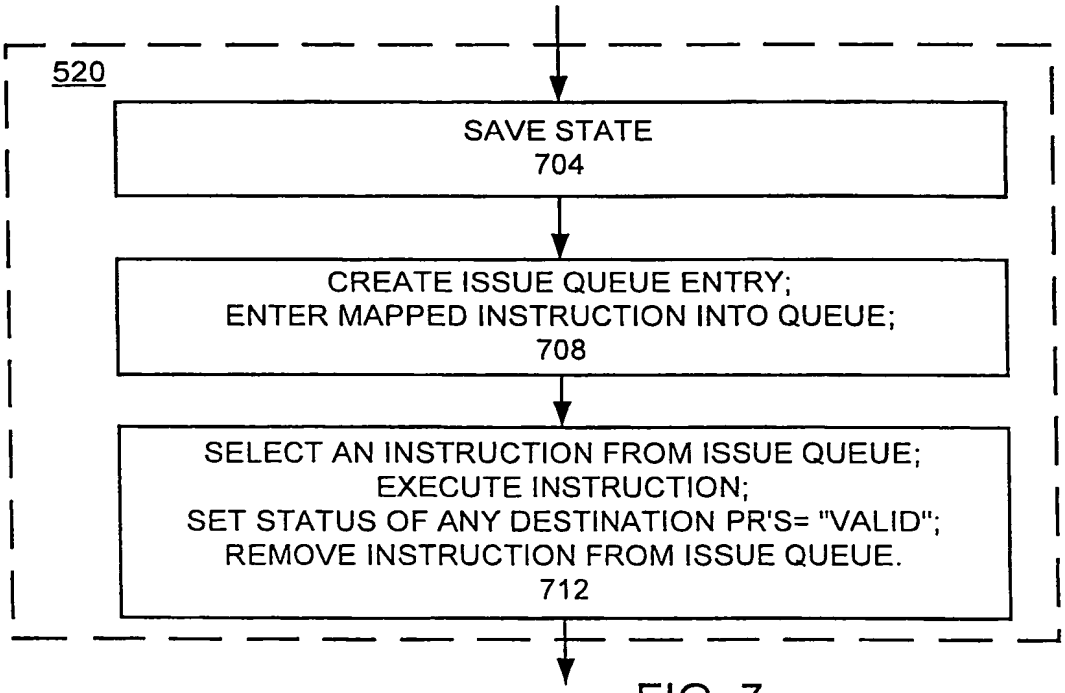

520
SAVE STATE 704
CREATE ISSUE QUEUE ENTRY; ENTER MAPPED INSTRUCTION INTO QUEUE; 708
SELECT AN INSTRUCTION FROM ISSUE QUEUE; EXECUTE INSTRUCTION; SET STATUS OF ANY DESTINATION PR'S= "VALID"; REMOVE INSTRUCTION FROM ISSUE QUEUE. 712

FIG. 7

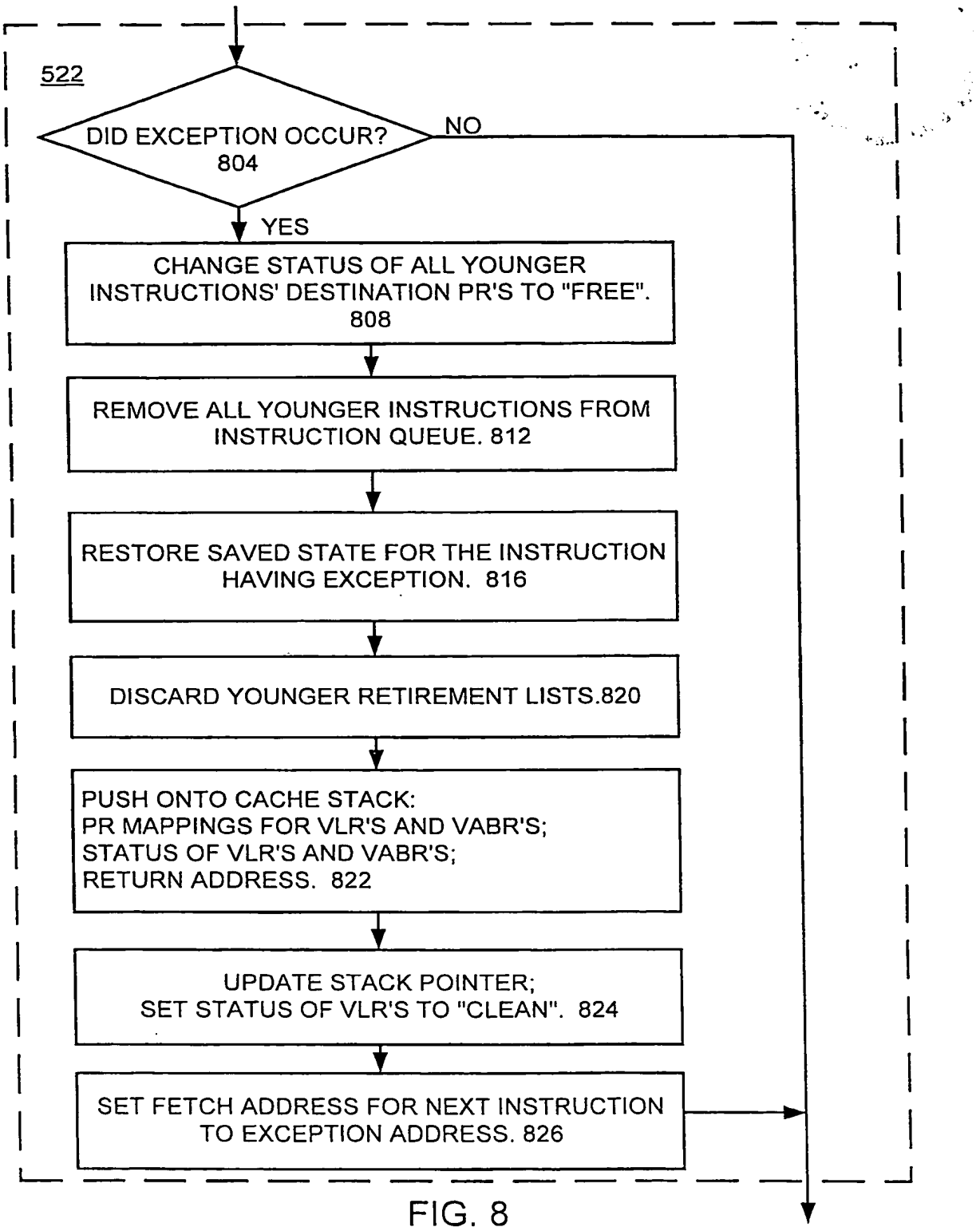

522
DID EXCEPTION OCCUR?
804
NO
YES
CHANGE STATUS OF ALL YOUNGER INSTRUCTIONS' DESTINATION PR'S TO "FREE". 808
REMOVE ALL YOUNGER INSTRUCTIONS FROM INSTRUCTION QUEUE. 812
RESTORE SAVED STATE FOR THE INSTRUCTION HAVING EXCEPTION. 816
DISCARD YOUNGER RETIREMENT LISTS.820
PUSH ONTO CACHE STACK:
PR MAPPINGS FOR VLR'S AND VABR'S;
STATUS OF VLR'S AND VABR'S;
RETURN ADDRESS. 822
UPDATE STACK POINTER;
SET STATUS OF VLR'S TO "CLEAN". 824
SET FETCH ADDRESS FOR NEXT INSTRUCTION TO EXCEPTION ADDRESS. 826

FIG. 8

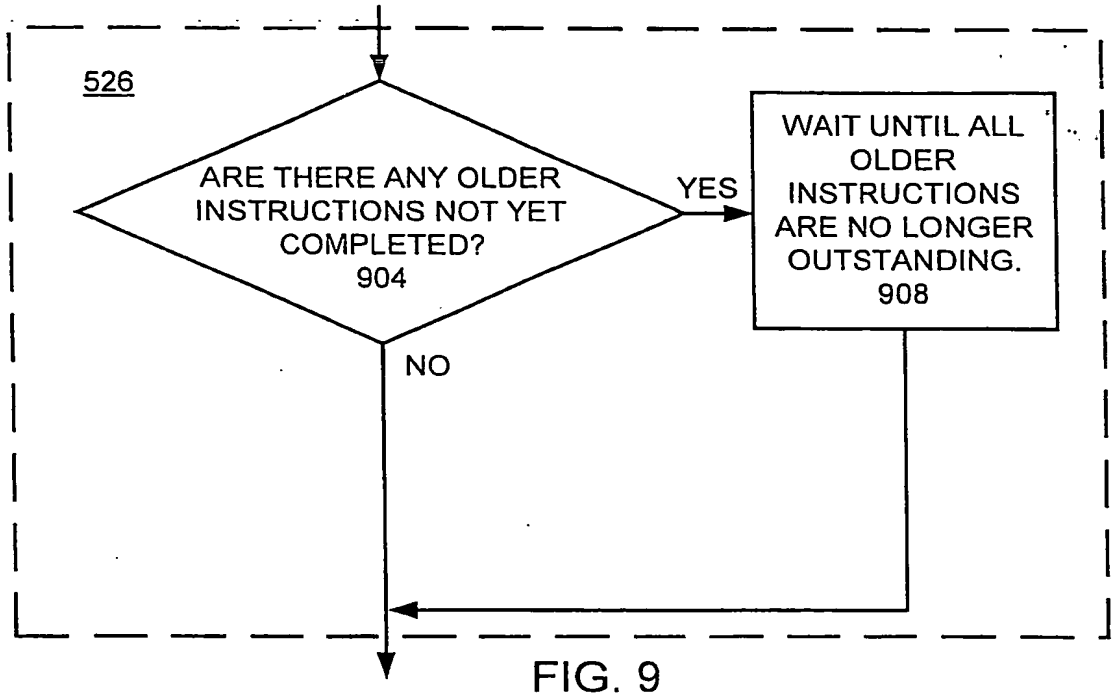

526
ARE THERE ANY OLDER INSTRUCTIONS NOT YET COMPLETED? 904
YES
WAIT UNTIL ALL OLDER INSTRUCTIONS ARE NO LONGER OUTSTANDING. 908
NO

FIG. 9

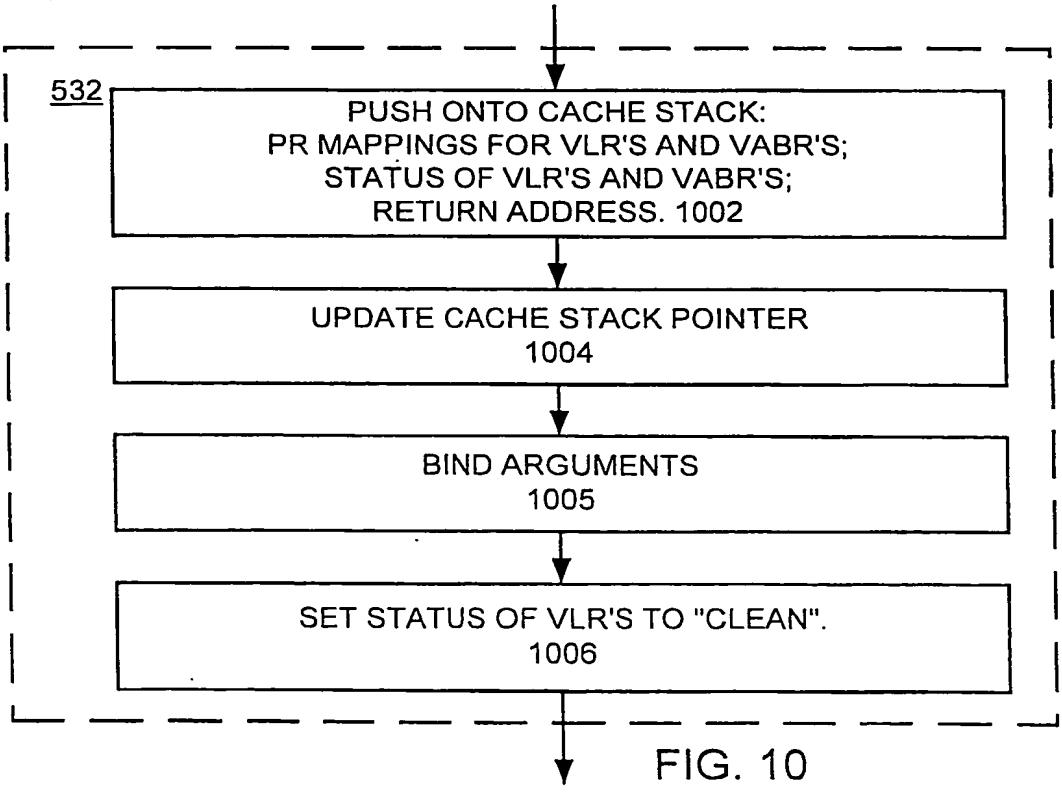

532
PUSH ONTO CACHE STACK: PR MAPPINGS FOR VLR'S AND VABR'S; STATUS OF VLR'S AND VABR'S; RETURN ADDRESS. 1002
UPDATE CACHE STACK POINTER 1004
BIND ARGUMENTS 1005
SET STATUS OF VLR'S TO "CLEAN". 1006

FIG. 10

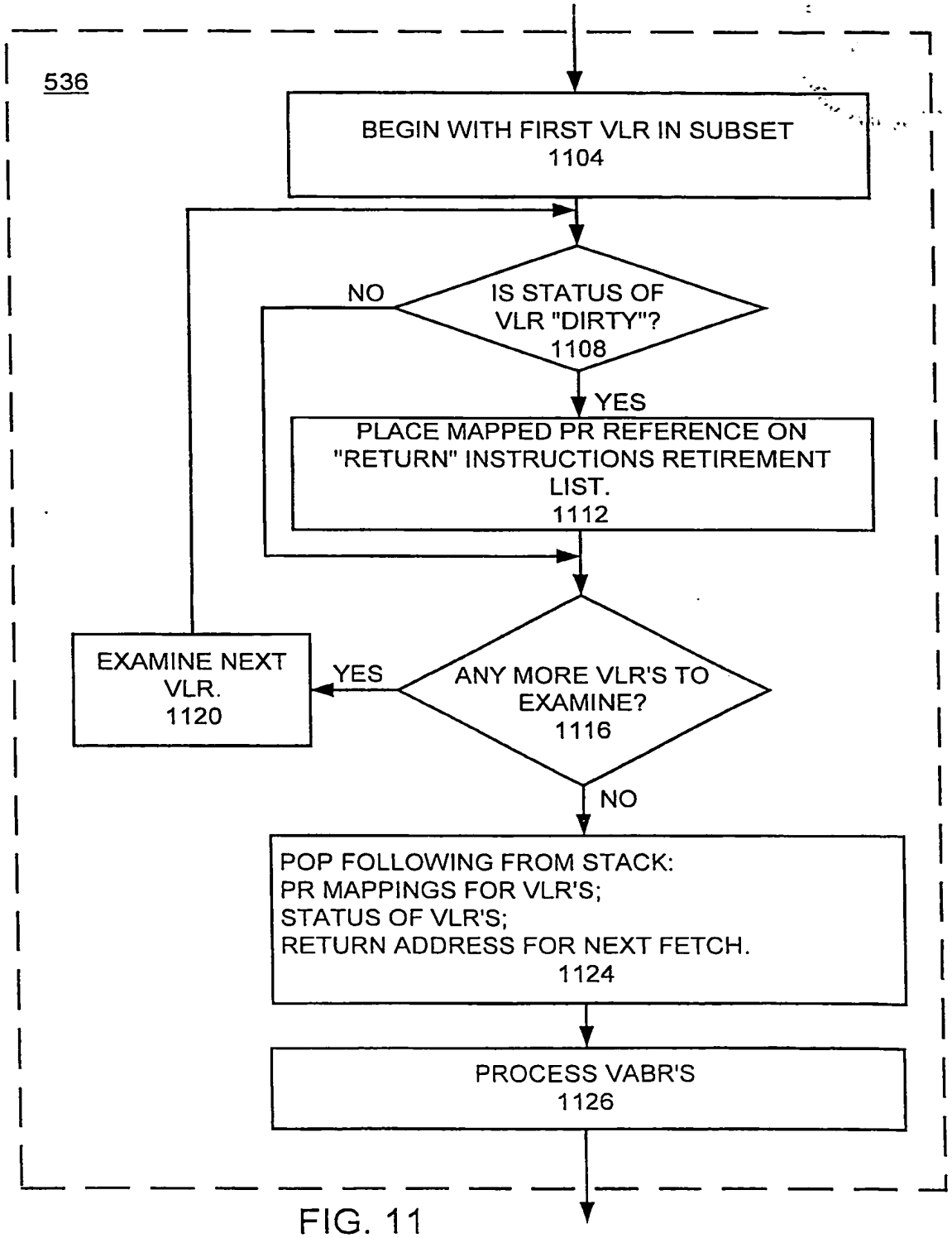

536
BEGIN WITH FIRST VLR IN SUBSET
1104
IS STATUS OF VLR "DIRTY"?
1108
NO
YES
PLACE MAPPED PR REFERENCE ON "RETURN" INSTRUCTIONS RETIREMENT LIST.
1112
ANY MORE VLR'S TO EXAMINE?
1116
YES
EXAMINE NEXT VLR.
1120
NO
POP FOLLOWING FROM STACK:
PR MAPPINGS FOR VLR'S;
STATUS OF VLR'S;
RETURN ADDRESS FOR NEXT FETCH.
1124
PROCESS VABR'S
1126

FIG. 11

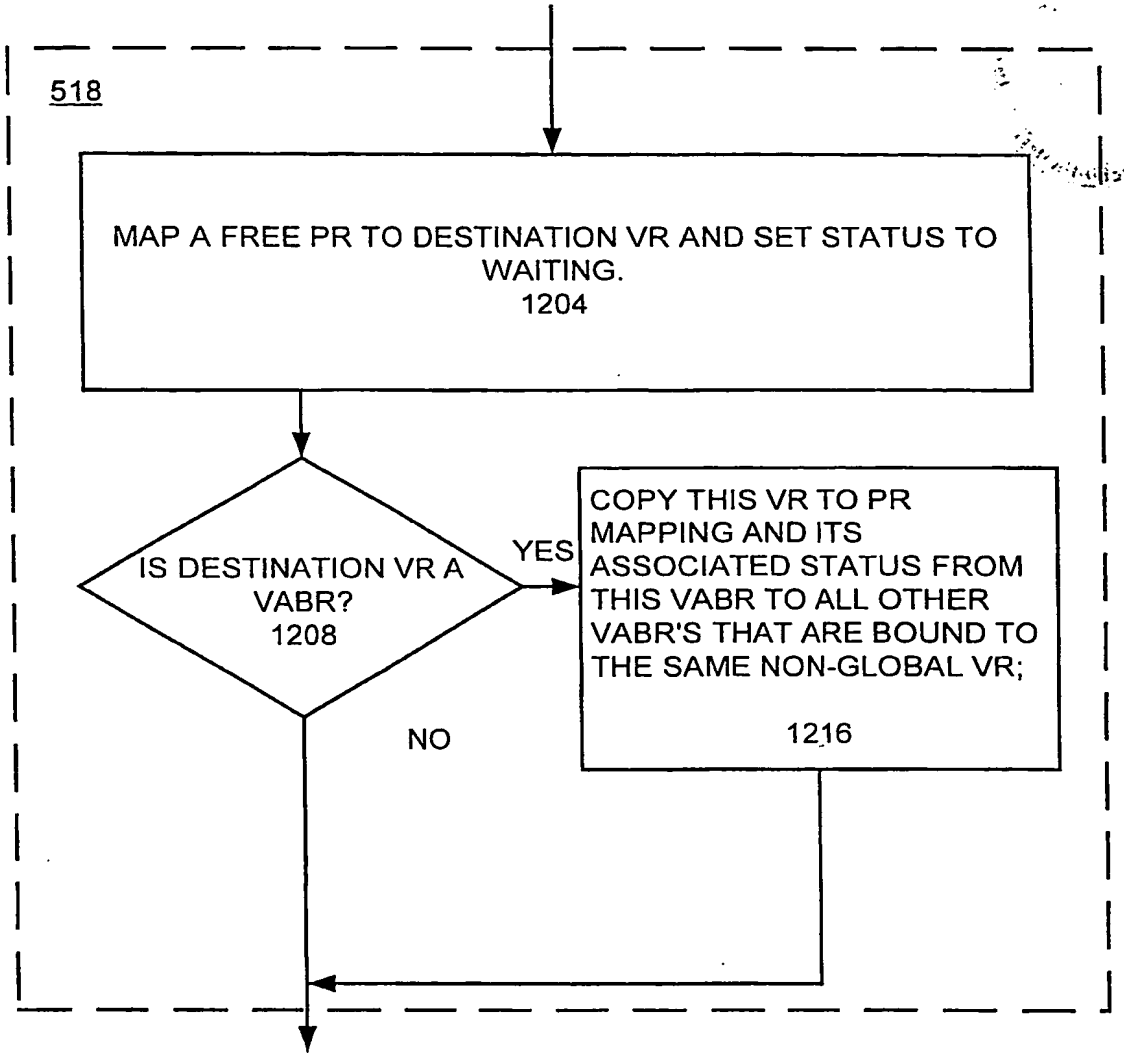

518
MAP A FREE PR TO DESTINATION VR AND SET STATUS TO WAITING.
1204
IS DESTINATION VR A VABR?
1208
YES
NO
COPY THIS VR TO PR MAPPING AND ITS ASSOCIATED STATUS FROM THIS VABR TO ALL OTHER VABR'S THAT ARE BOUND TO THE SAME NON-GLOBAL VR;
1216

FIG. 12

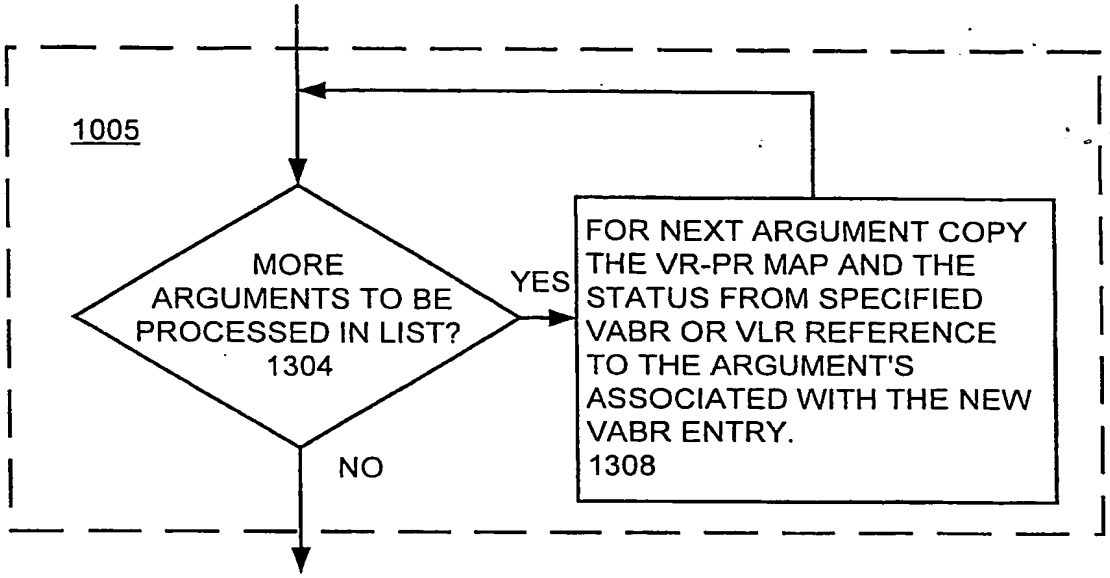

1005
MORE ARGUMENTS TO BE PROCESSED IN LIST? 1304
YES
NO
FOR NEXT ARGUMENT COPY THE VR-PR MAP AND THE STATUS FROM SPECIFIED VABR OR VLR REFERENCE TO THE ARGUMENT'S ASSOCIATED WITH THE NEW VABR ENTRY. 1308

FIG. 13

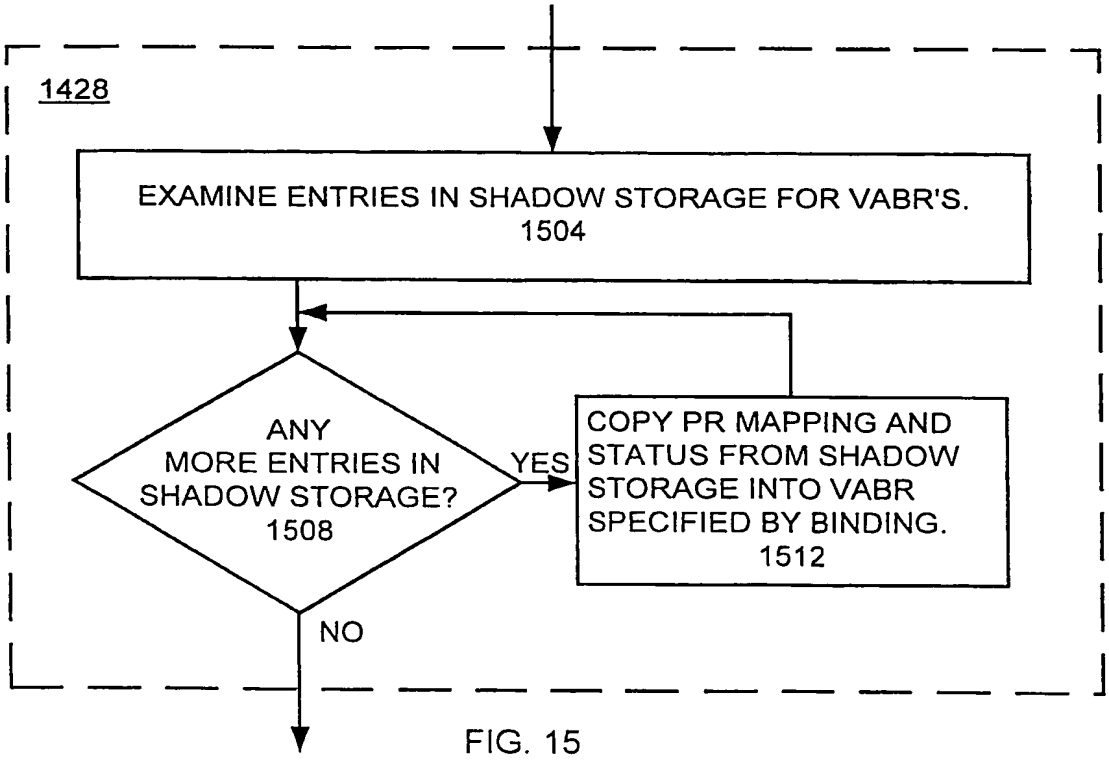

1428
EXAMINE ENTRIES IN SHADOW STORAGE FOR VABR'S. 1504
ANY MORE ENTRIES IN SHADOW STORAGE? 1508
YES
NO
COPY PR MAPPING AND STATUS FROM SHADOW STORAGE INTO VABR SPECIFIED BY BINDING. 1512

FIG. 15

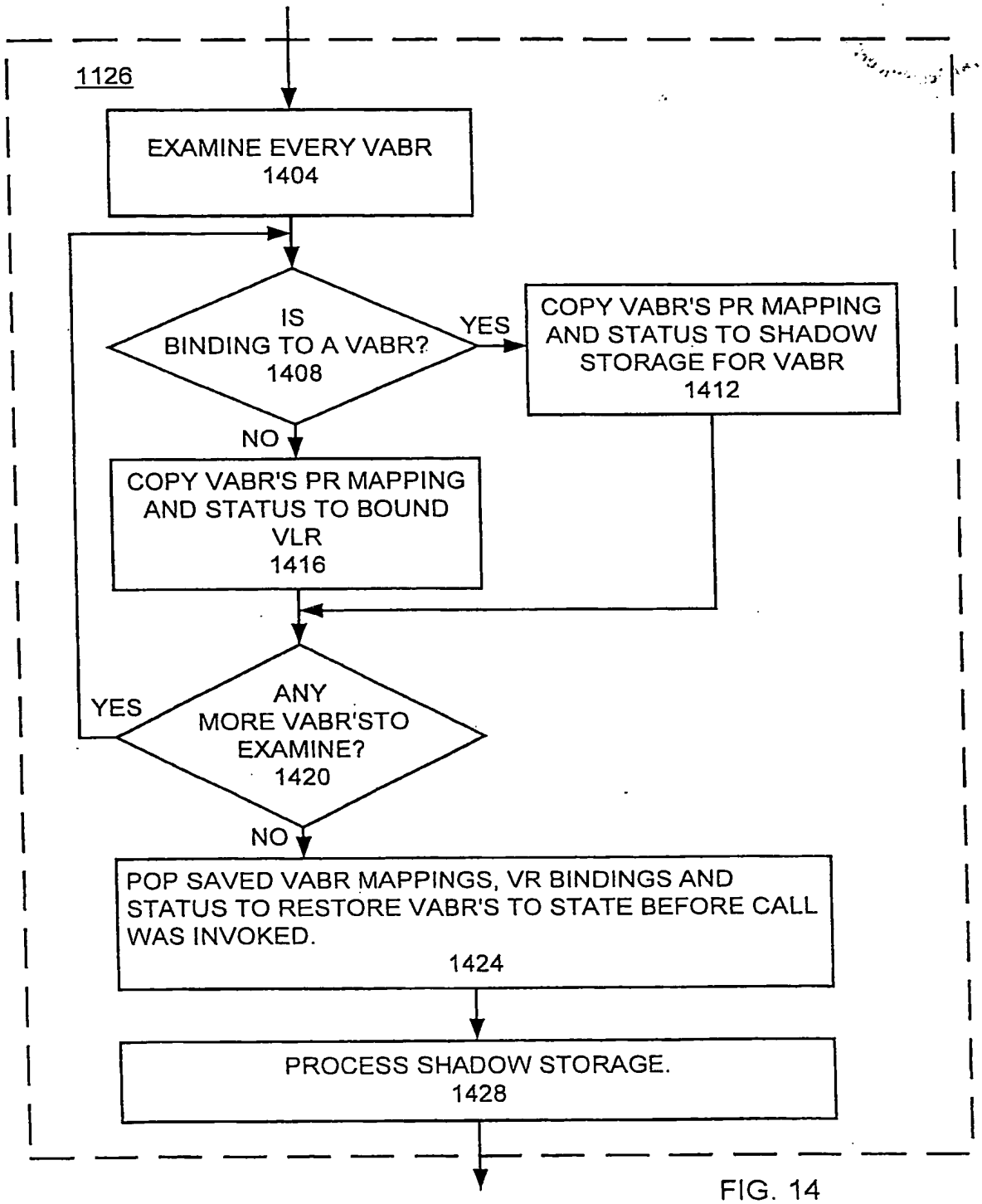

1126
EXAMINE EVERY VABR
1404
IS
BINDING TO A VABR?
1408
YES
COPY VABR'S PR MAPPING
AND STATUS TO SHADOW
STORAGE FOR VABR
1412
NO
COPY VABR'S PR MAPPING
AND STATUS TO BOUND
VLR
1416
ANY
MORE VABR'STO
EXAMINE?
1420
YES
NO
POP SAVED VABR MAPPINGS, VR BINDINGS AND
STATUS TO RESTORE VABR'S TO STATE BEFORE CALL
WAS INVOKED.
1424
PROCESS SHADOW STORAGE.
1428

FIG. 14

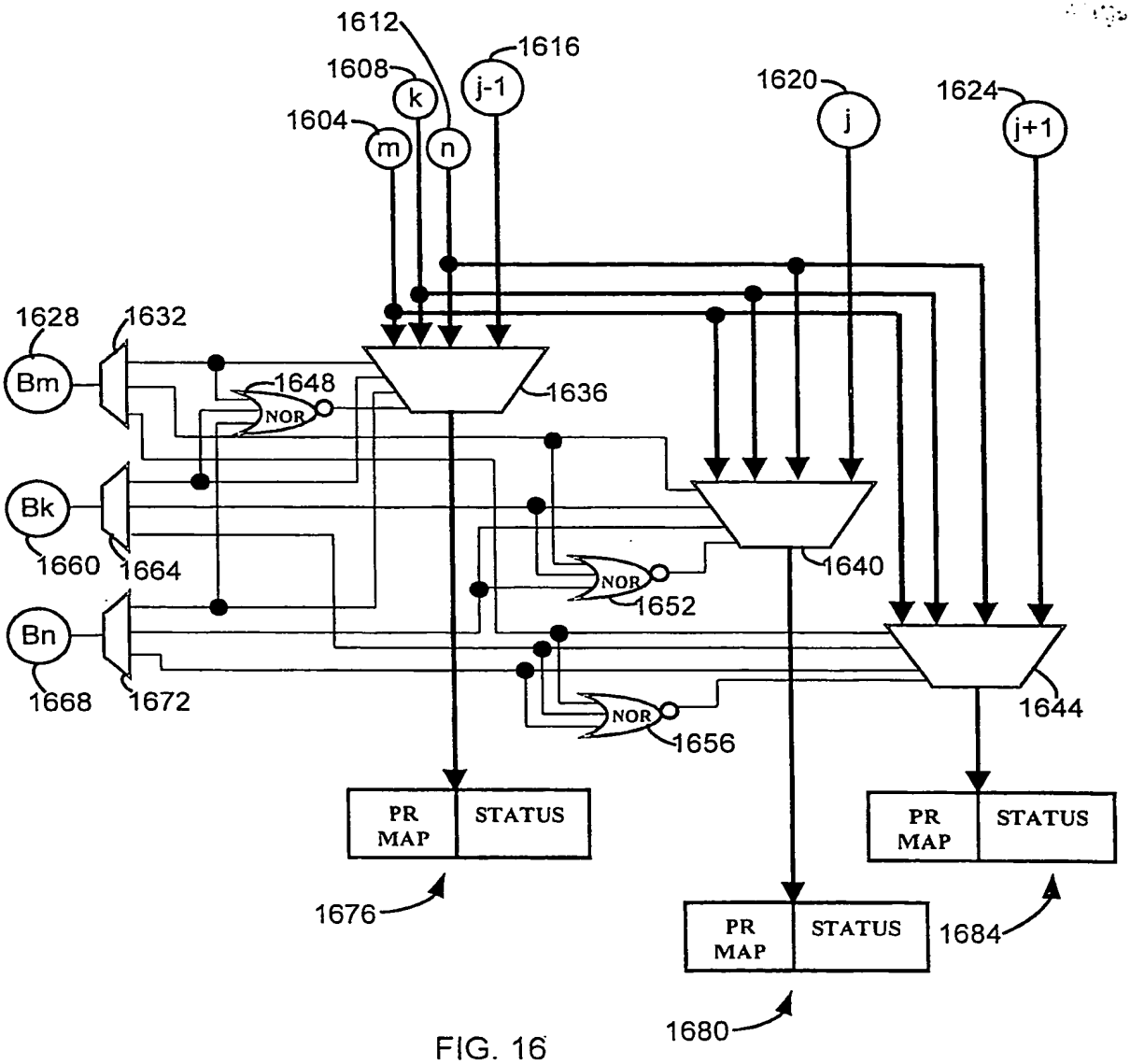

1612
1616
1608
k
j-1
1604
m
n
1620
j
1624
j+1
1628
1632
Bm
1648
NOR
1636
Bk
1660
1664
1640
NOR
1652
Bn
1668
1672
1644
NOR
1656
PR MAP
STATUS
1676
PR MAP
STATUS
1684
PR MAP
STATUS
1680

FIG. 16

5 STAGE PIPELINE STAGE

FIG. 17

EXAMPLE PROGRAM

```
A:      ADD VR6, VR3, VR10
        SUB VR2, VR3, VR8
        MUL VR8, VR1, VR7
        CALL B
        ADD VR8, VR7, VR2
        RET
B:      ADD VR1, VR2, VR6
        ADD VR3, VR7, VR7
        MUL VR6, VR7, VR1
        RET
```

start of example execution

```
        ADD VR0, VR2, VR4
        LIM VR8, #22
        SUB VR3, VR2, VR3
        ADD VR4, VR3, VR3
        MUL VR4, VR5, VR6
        CALL A
        ADD VR8, VR1, VR1
        ADD VR8, VR2, VR2
```

end of example execution

FIG. 18

CLOCK 1: DECODE STAGE

INITIAL PHYSICAL REGISTER STATE

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	DESCRIPTION
0	0	1	3	EXAMPLE INITIALIZATION
1	0	1	5	EXAMPLE INITIALIZATION
2	0	1	7	EXAMPLE INITIALIZATION
3	0	1	9	EXAMPLE INITIALIZATION
4	0	1	11	EXAMPLE INITIALIZATION
5	0	1	13	EXAMPLE INITIALIZATION
6	0	1	15	EXAMPLE INITIALIZATION
7	0	1	17	EXAMPLE INITIALIZATION
8	0	1	19	EXAMPLE INITIALIZATION
9	0	1	21	EXAMPLE INITIALIZATION
10	0	1	23	EXAMPLE INITIALIZATION
11	0	1	25	EXAMPLE INITIALIZATION
12	0	1	27	EXAMPLE INITIALIZATION
13	0	1	29	EXAMPLE INITIALIZATION
14	0	1	31	EXAMPLE INITIALIZATION
15	0	1	33	EXAMPLE INITIALIZATION
16	1	-	-	UNALLOCATED
17	1	-	-	UNALLOCATED
18	1	-	-	UNALLOCATED
19	1	-	-	UNALLOCATED
20	1	-	-	UNALLOCATED
21	1	-	-	UNALLOCATED
22	1	-	-	UNALLOCATED
23	1	-	-	UNALLOCATED
24	1	-	-	UNALLOCATED
ETC.	1	-	-	UNALLOCATED

FIG. 19

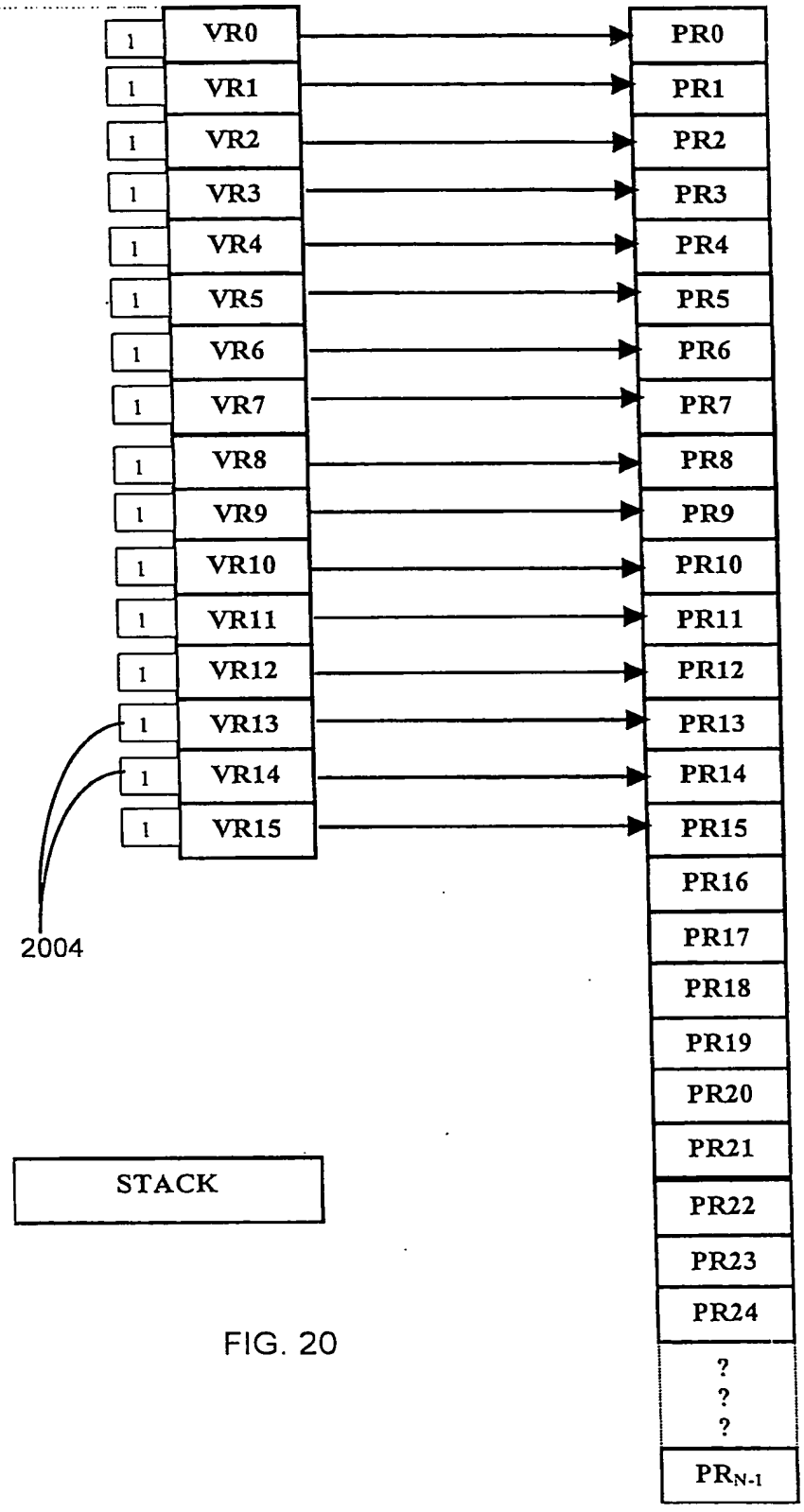

Initial Mapping States
1
VR0
VR1
VR2
VR3
VR4
VR5
VR6
VR7
VR8
VR9
VR10
VR11
VR12
VR13
VR14
VR15
PR0
PR1
PR2
PR3
PR4
PR5
PR6
PR7
PR8
PR9
PR10
PR11
PR12
PR13
PR14
PR15
PR16
PR17
PR18
PR19
PR20
PR21
PR22
PR23
PR24
?
?
?
PRN-1
2004
STACK

FIG. 20

INSTRUCTION NUMBER	INSTRUCTION	DESCRIPTION	EFFECT OF INSTRUCTION
1	ADD VR0, VR2, VR4	VR0 + VR2 → VR4	10 → VR4
2	LIM VR8, #22	22 → VR8	22_{10} → VR8
3	SUB VR3, VR2, VR3	VR3 – VR2 → VR3	2 → VR3
4	ADD VR4, VR3, VR3	VR4 + VR3 → VR3	12 → VR3
5	MUL VR4, VR5, VR6	VR4 * VR5 → VR6	130 → VR6
6	CALL A	CALL subroutine A	VR6—VR9 available as scratch registers
7	ADD VR6, VR3, VR10	VR6 + VR3 → VR10	142 → VR10
8	SUB VR2, VR3, VR8	VR2 –VR3 → VR8	-5 → VR8 (use VR8 as scratch register)
9	MUL VR8, VR1, VR7	VR8 * VR1 → VR7	-25 → VR7 (use VR7 as scratch register)
10	CALL B	CALL subroutine B	VR6—VR9 available as scratch registers
11	ADD VR1, VR2, VR6	VR1 + VR2 → VR6	12 → VR6 (use VR6 as scratch register)
12	ADD VR3, VR7, VR7	VR3 + VR7 → VR7	-13 → VR7 (use VR7 as scratch register)
13	MUL VR6, VR7, VR1	VR6 * VR7 → VR1	-156 → VR1
14	RET	RETURN	restore value of 130 to VR6 and –25 to VR7
15	ADD VR8, VR7, VR1	VR8 + VR7 → VR2	-30 → VR2
16	RET	RETURN	restore value of 17 to VR7 and 22 to VR8
17	ADD VR8, VR1, VR1	VR8 + VR1 → VR1	-134 → VR1
18	ADD VR8, VR2, VR2	VR8 + VR2 → VR2	-8 → VR2

EXAMPLE INSTRUCTION FLOW

FIG. 21

INSTRUCTION NUMBER	VIRTUAL REGISTER NUMBER: INSTRUCTION / INITIAL VALUE:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33
1	ADD VR0, VR2, VR4	3	5	7	9	10	13	15	17	19	21	23	25	27	29	31	33
2	LIM VR8, #22	3	5	7	9	10	13	15	17	22	21	23	25	27	29	31	33
3	SUB VR3, VR2, VR3	3	5	7	2	10	13	15	17	22	21	23	25	27	29	31	33
4	ADD VR4, VR3, VR3	3	5	7	12	10	13	15	17	22	21	23	25	27	29	31	33
5	MUL VR4, VR5, VR6	3	5	7	12	10	13	130	17	22	21	23	25	27	29	31	33
6	CALL A	3	5	7	12	10	13	130	17	22	21	23	25	27	29	31	33
7	ADD VR6, VR3, VR10	3	5	7	12	10	13	130	17	22	21	142	25	27	29	31	33
8	SUB VR2, VR3, VR8	3	5	7	12	10	13	130	17	-5	21	142	25	27	29	31	33
9	MUL VR8, VR1, VR7	3	5	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33
10	CALL B	3	5	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33
11	ADD VR1, VR2, VR6	3	5	7	12	10	13	12	-25	-5	21	142	25	27	29	31	33
12	ADD VR3, VR7, VR7	3	5	7	12	10	13	12	-13	-5	21	142	25	27	29	31	33
13	MUL VR6, VR7, VR1	3	-156	7	12	10	13	12	-13	-5	21	142	25	27	29	31	33
14	RET	3	-156	7	12	10	13	130	-25	-5	21	142	25	27	29	31	33
15	ADD VR8, VR7, VR1	3	-156	-30	12	10	13	130	-25	-5	21	142	25	27	29	31	33
16	RET	3	-156	-30	12	10	13	130	17	22	21	142	25	27	29	31	33
17	ADD VR8, VR1, VR1	3	-134	-30	12	10	13	130	17	22	21	142	25	27	29	31	33
18	ADD VR8, VR2, VR2	3	-134	-8	12	10	13	130	17	22	21	142	25	27	29	31	33

CONTENTS OF VIRTUAL REGISTERS AS INSTRUCTIONS EXECUTE

FIG. 22

Clock 1			
Fetch instr. 1, 2.			
Clock 2			
Fetch instr. 3, 4;	Decode instr. 1, 2.		
Clock 3			
Fetch instr. 5, 6;	Decode instr. 3, 4;	Read regs. PR0, PR2 for instr. 1.	
Clock 4			
Fetch instr. 7, 8;	Decode instr. 5, 6;	Read regs. PR2, PR3 for instr. 3; respectively. Execute instr. 6 (CALL A).	Execute instr. 1, 2 and store results in PR16, PR17
Clock 5			
Fetch instr. 9, 10;	Decode instr. 7, 8;	Read regs. PR5, PR16 for instr. 5;	Execute instr. 3; store result in PR18. Retire instr. 1, 2.
Clock 6			
Fetch instr. 11, 12;	Decode instr. 9, 10;	Read regs. PR16, PR18 for instr. 4;	Execute instr. 5 and store result in PR20; Execute instr. 10 (CALL B); Retire instr. 3.
Clock 7			
Fetch instr. 13, 14;	Decode instr. 11, 12;		Execute instr. 4 and store result in PR19.
Clock 8			
Fetch instr. 15, 16;	Decode instr. 13, 14;	Read regs. PR2, PR19, PR20 for instr. 7, 8;	Execute instr 14(Return). Retire instr. 4, 5, 6.
Clock 9			
Fetch instr. 17, 18;	Decode instr. 15, 16;	Read regs. PR1, PR2, PR19 for instr. 9 and 11;	Execute instr. 7 and 8 and store results in PR21 and PR22 respectively. Execute instr. 16(Return).

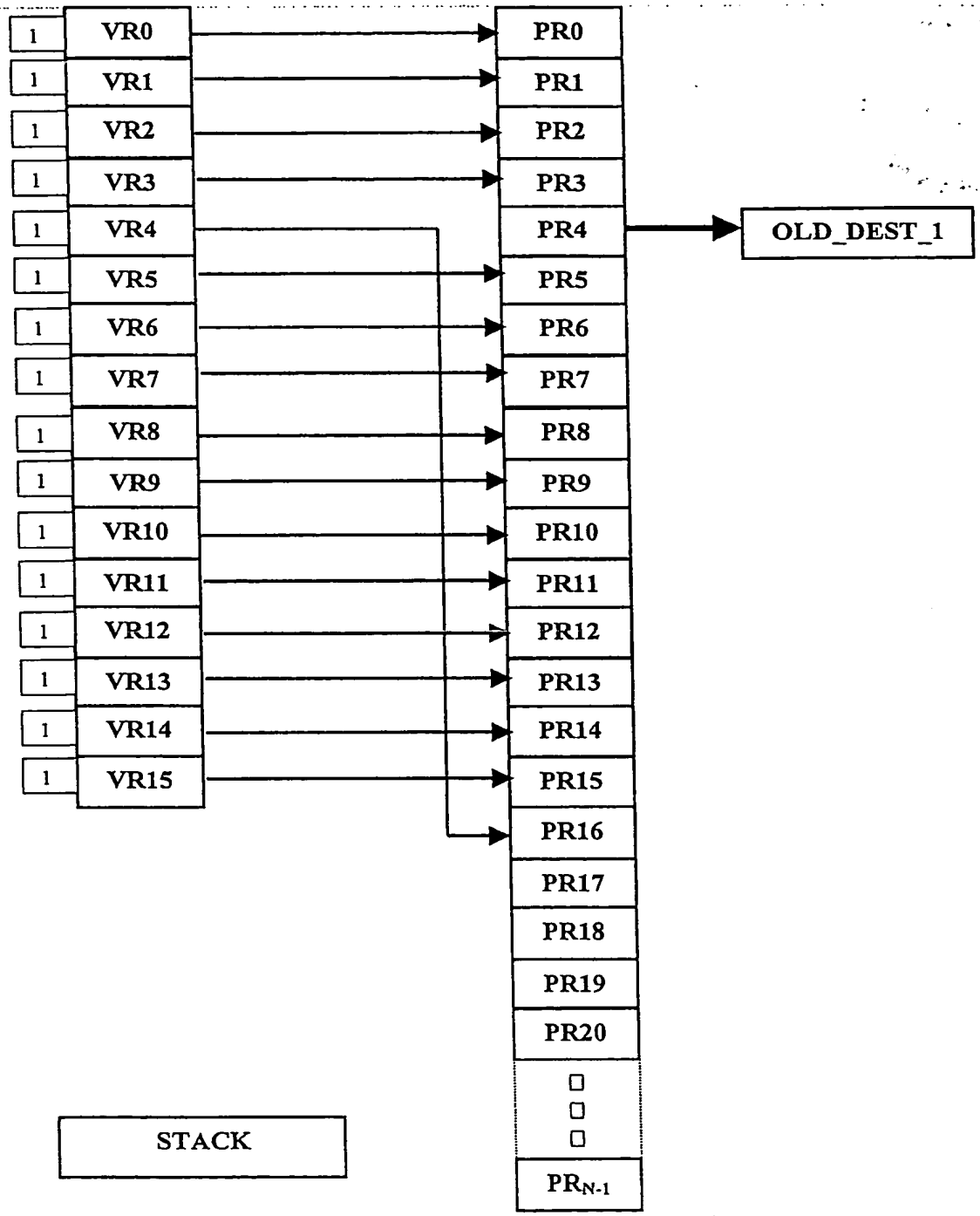
Clock by Clock Pipeline Description

FIG. 23A

Clock 10	Decode instr. 17, 18;		Execute instr. 9 and 11 and store results in PR4 and PR8 respectively.
Clock 11		Read regs. PR4, PR19, PR22 for instr. 12 and 15;	Retire instr. 9, 10, 11.
Clock 12		Read regs. PR2, PR6, PR17 for instr. 17 and 18;	Execute instr. 12, 15 and store results in PR3 and PR6 respectively.
Clock 13		Read regs. PR3, PR8 for instr. 13;	Execute instr. 17, 18 and store results in PR18 and PR24 respectively; Retire instr. 12.
Clock 14			Execute instr. 13 and store results in PR23.
Clock 15			Retire instr. 13, 14, 15, 16, 17, 18.

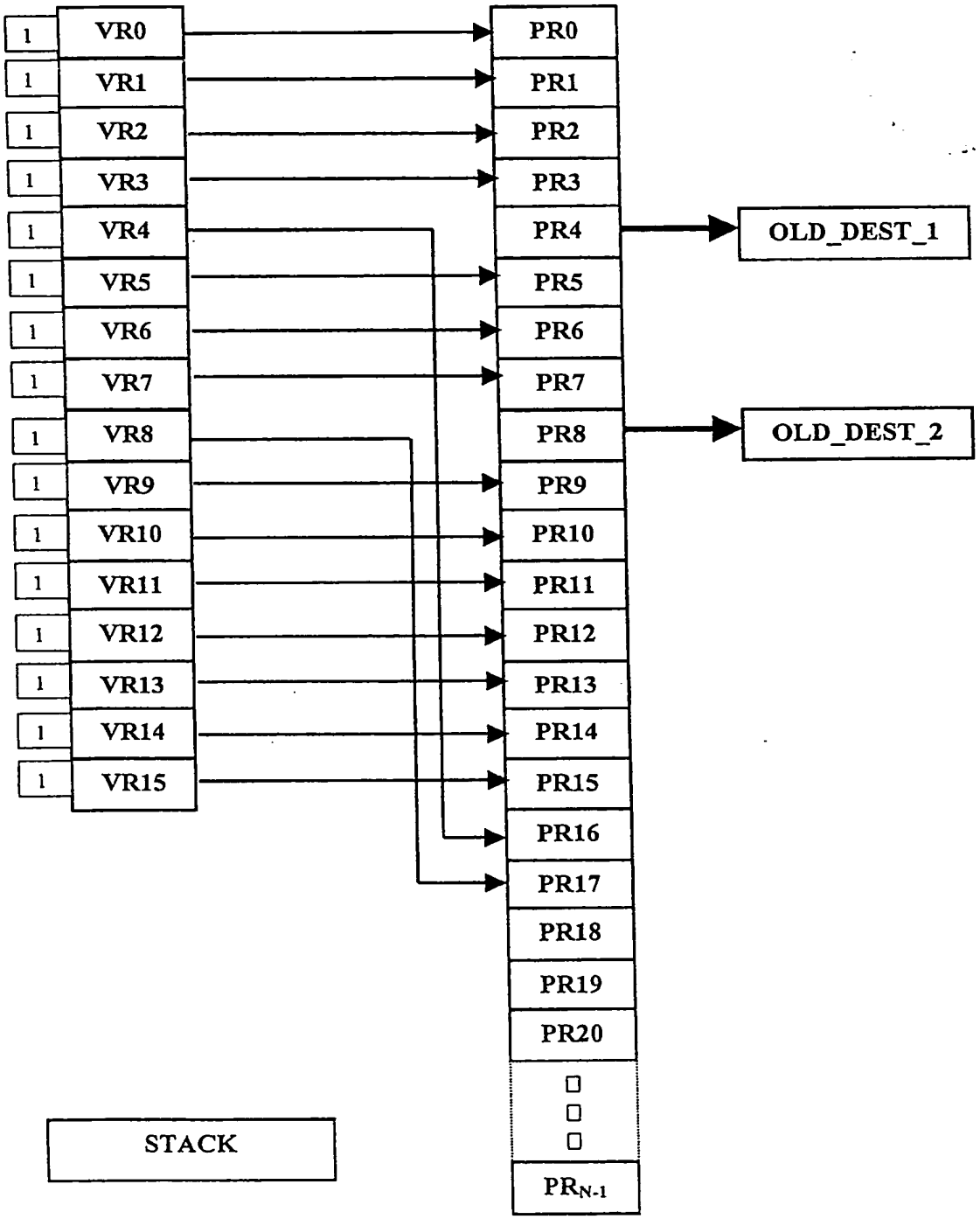
Clock by Clock Pipeline Description

FIG. 23B



INSTR. 1: ADD VR0, VR2, VR4 maps to PR0 + PR2 → PR16, PR4 → OLD_DEST_1

FIG. 24



INSTR. 2: LIM VR8, #22 **maps to** LIM PR17, #22, PR8 → OLD_DEST_2

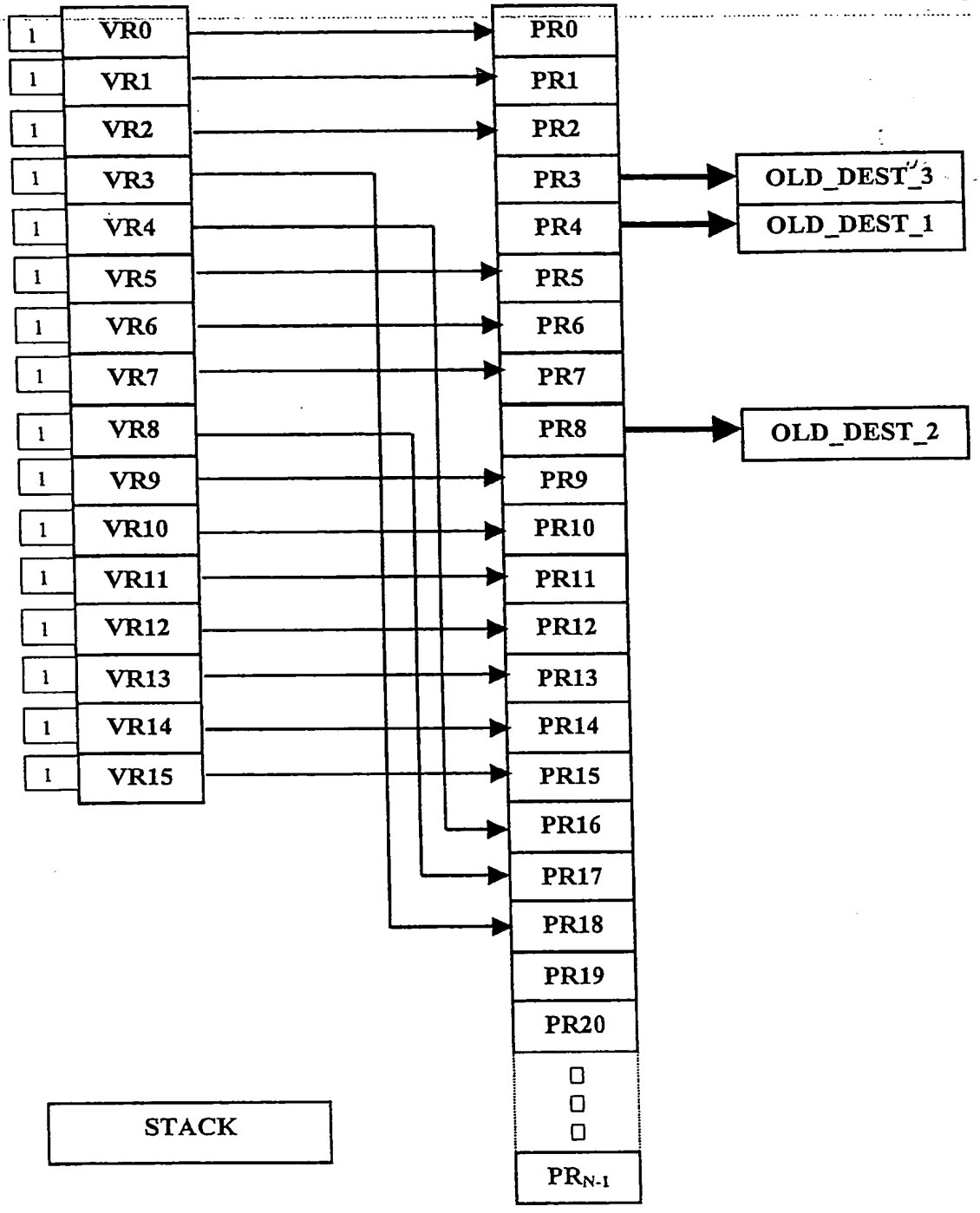
FIG. 25

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	3	EXAMPLE INITIALIZATION
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	UNALLOCATED
19	1	-	-	-	UNALLOCATED
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 2: DECODE STAGE

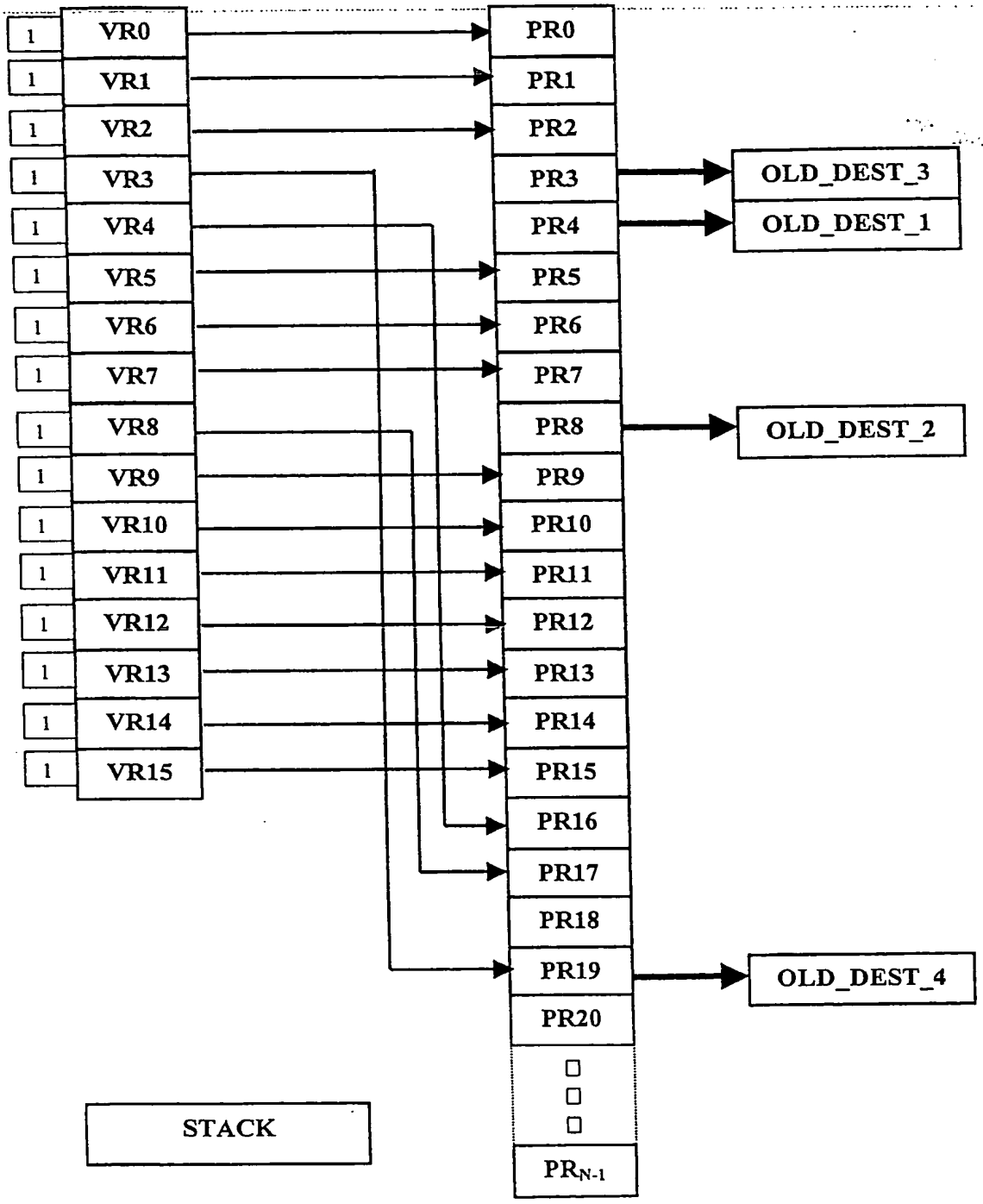
INSTRUCTIONS 1 & 2 PHYSICAL REGISTER STATE

FIG. 26



INSTR. 3: SUB VR3, VR2, VR3 **maps to** SUB PR3, PR2, PR18,
PR3 → OLD_DEST_3

FIG. 27



INSTR. 4: ADD VR4, VR3, VR3 **maps to** ADD PR16, PR18, PR19,
PR18 → OLD_DEST_4

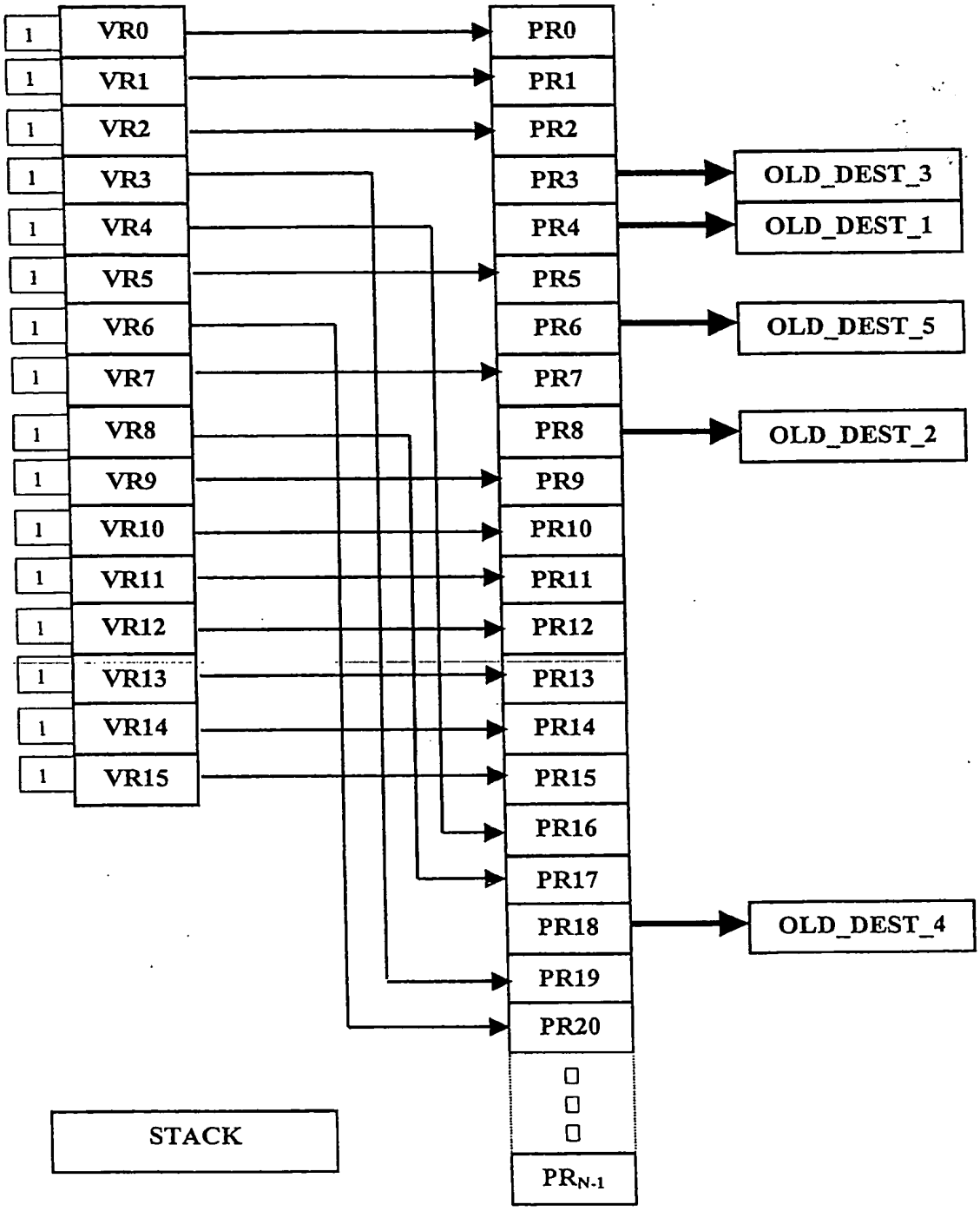
FIG. 28

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	WAITING FOR 3 TO EXECUTE & RETIRE
19	1	-	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 3: DECODE STAGE

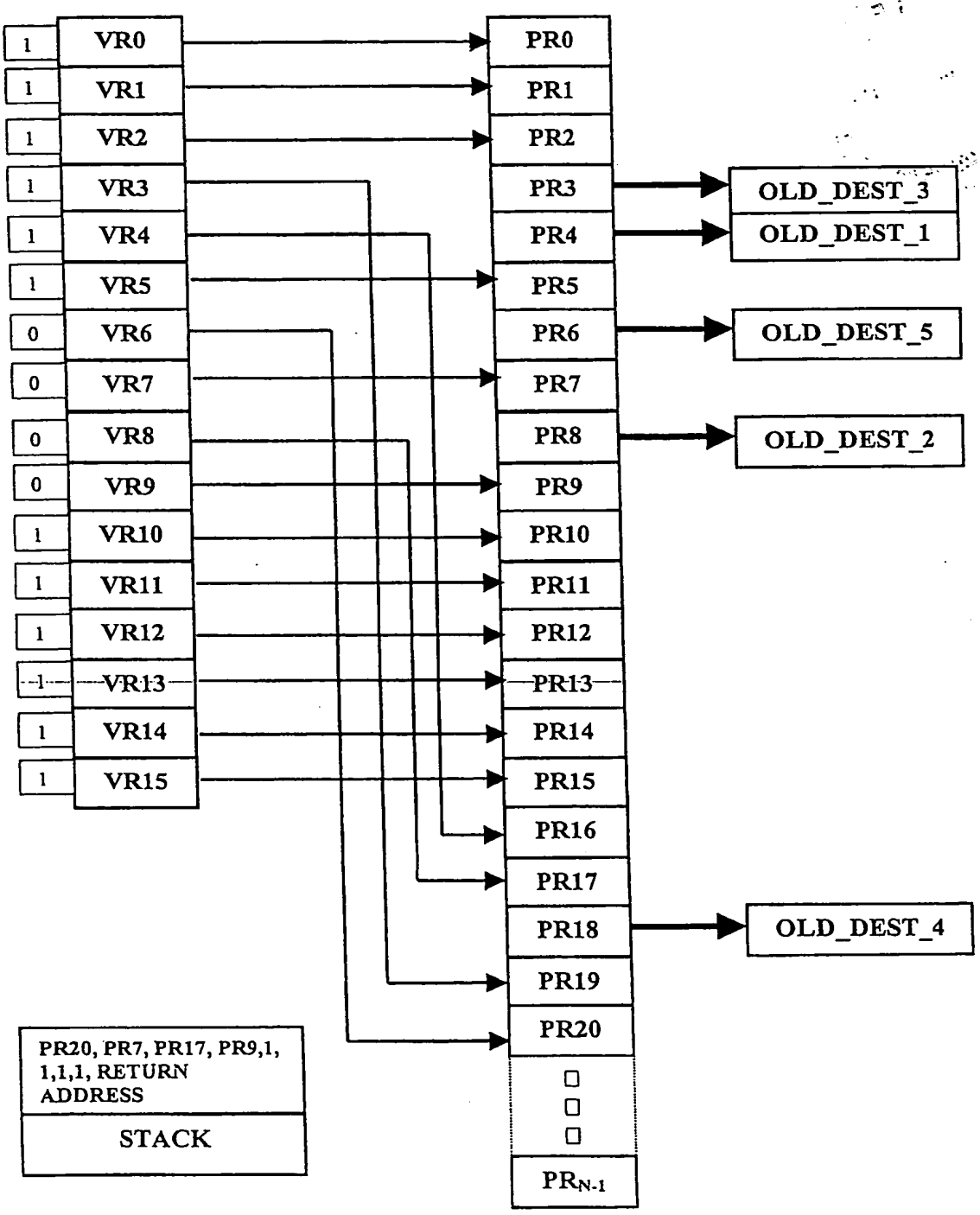
INSTRUCTIONS 3 & 4 PHYSICAL REGISTER STATE

FIG. 29



INSTR. 5: MUL VR4, VR5, VR6 **maps to** MUL PR16, PR5, PR20, PR6 → OLD_DEST_5

FIG. 30



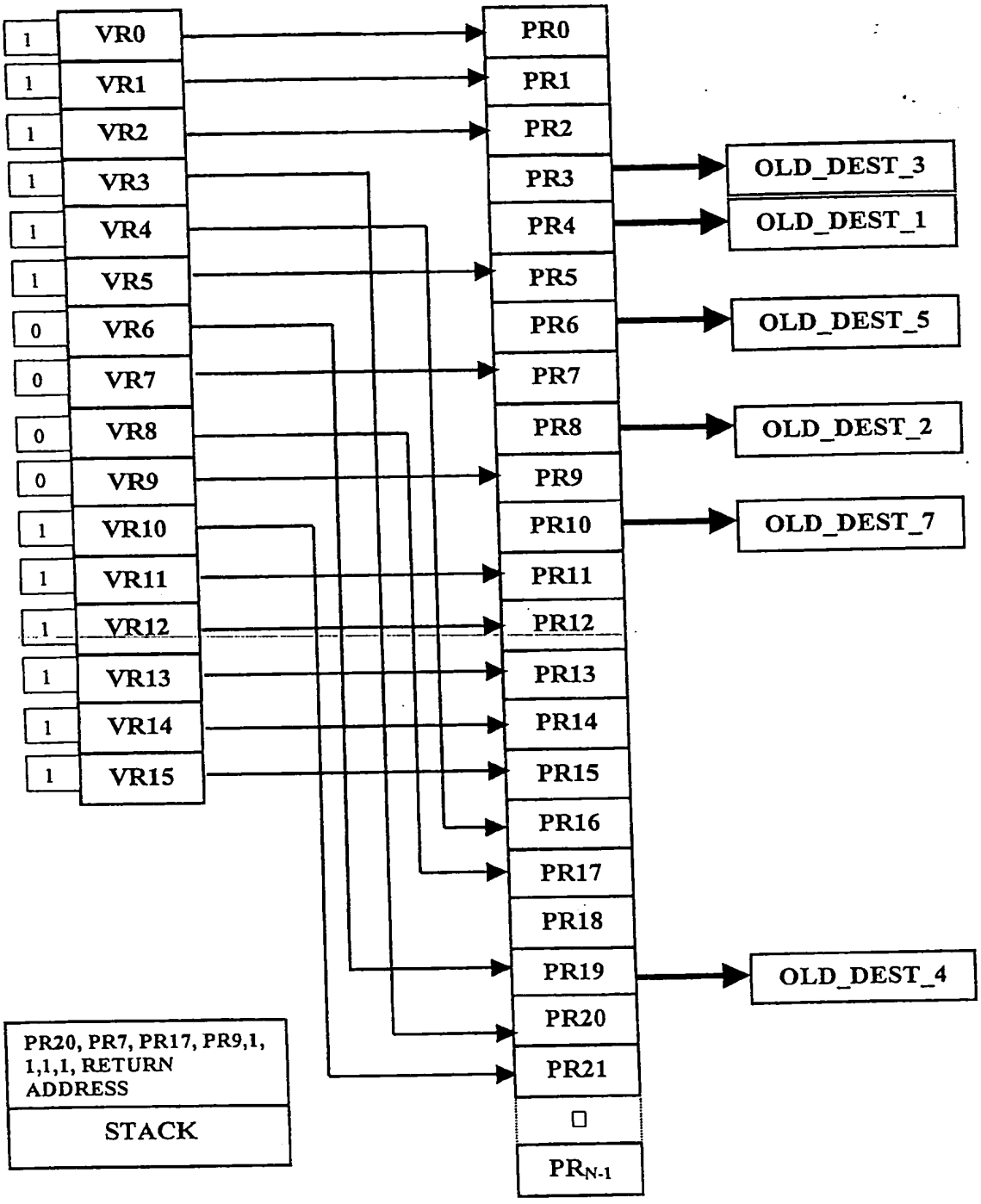
INSTR. 6: CALL A action PUSH PR20, PR7, PR17, PR9, 1, 1, 1, 1, RETURN ADDRESS, 0000 → DIRTY BITS FOR VR6-9, transfer to A

FIG. 31

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	INSTRUCTION 2 EXECUTED
18	0	-	-	-	WAITING FOR INST. 3 TO EXECUTE & RETIRE
19	0	-	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	-	-	6	WAITING FOR INSTRUCTION 5 TO EXECUTE
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

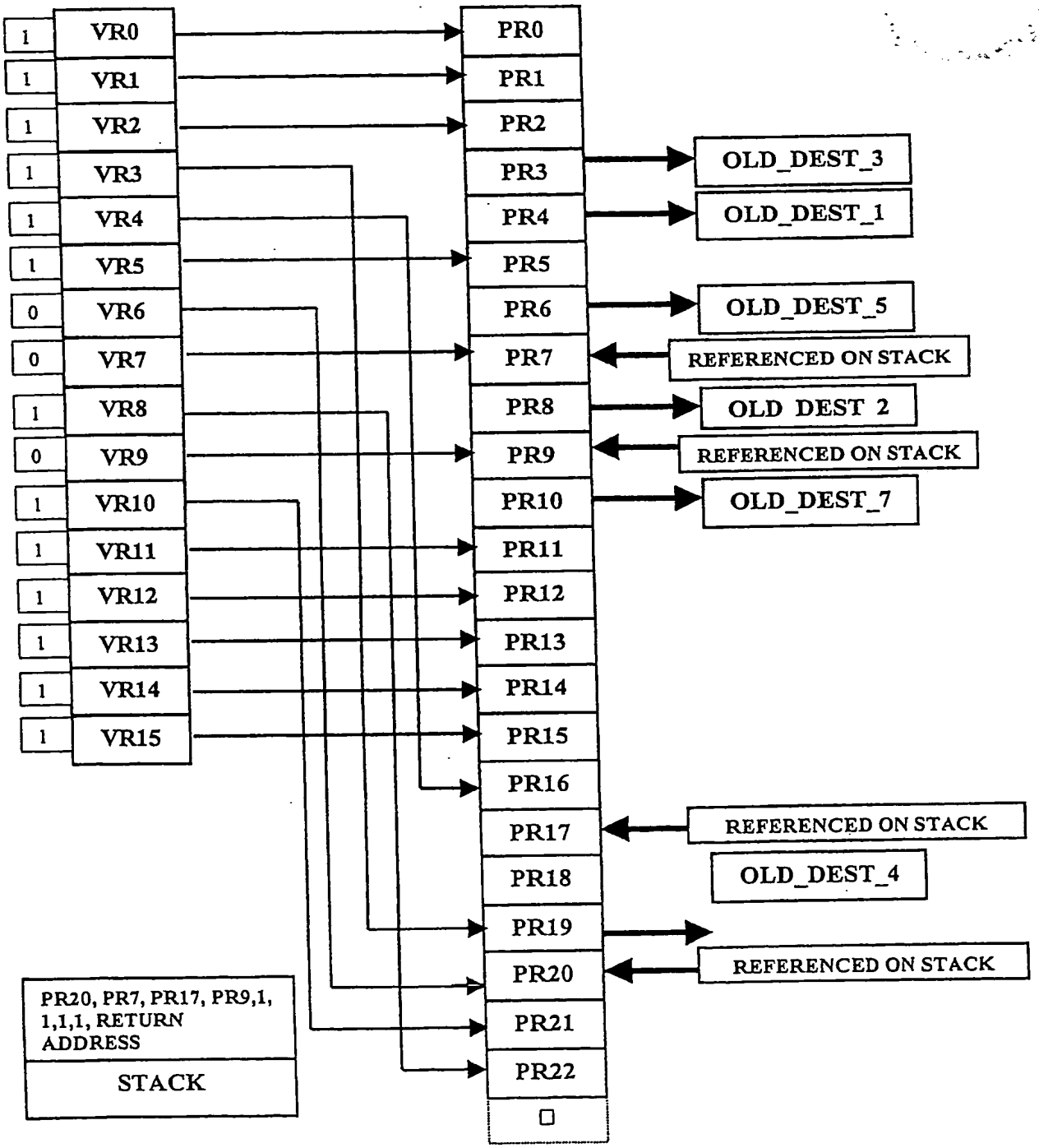
CLOCK 4: DECODE STAGE
INSTRUCTIONS 5 & 6 PHYSICAL REGISTER STATE

FIG. 32



INSTR. 7: ADD VR6, VR3, VR10 maps to ADD PR20, PR19, PR21, PR10 → OLD_DEST_7

FIG. 33



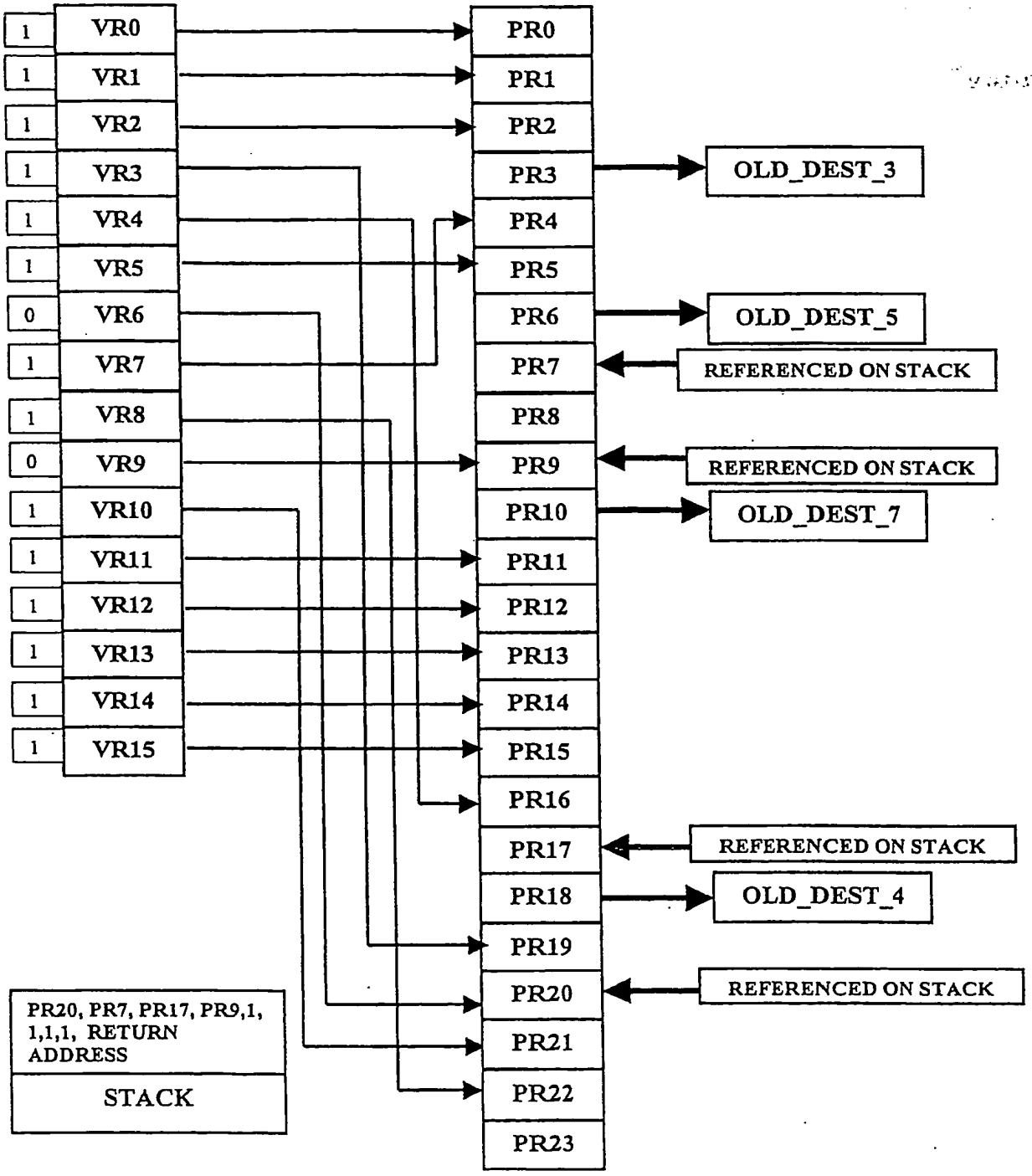
INSTR. 8: SUB VR2, VR3, VR8 maps to SUB PR2, PR19, PR22
1 → DIRTY BIT FOR VR8

FIG. 34

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	1	-	-	-	INSTRUCTION 1 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	EXAMPLE INITIALIZATION
8	1	-	-	-	INSTRUCTION 2 RETIRED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	INS. 3 EXECUTED WAITING FOR 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6	WAITING FOR INSTRUCTION 5 TO EXECUTE
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

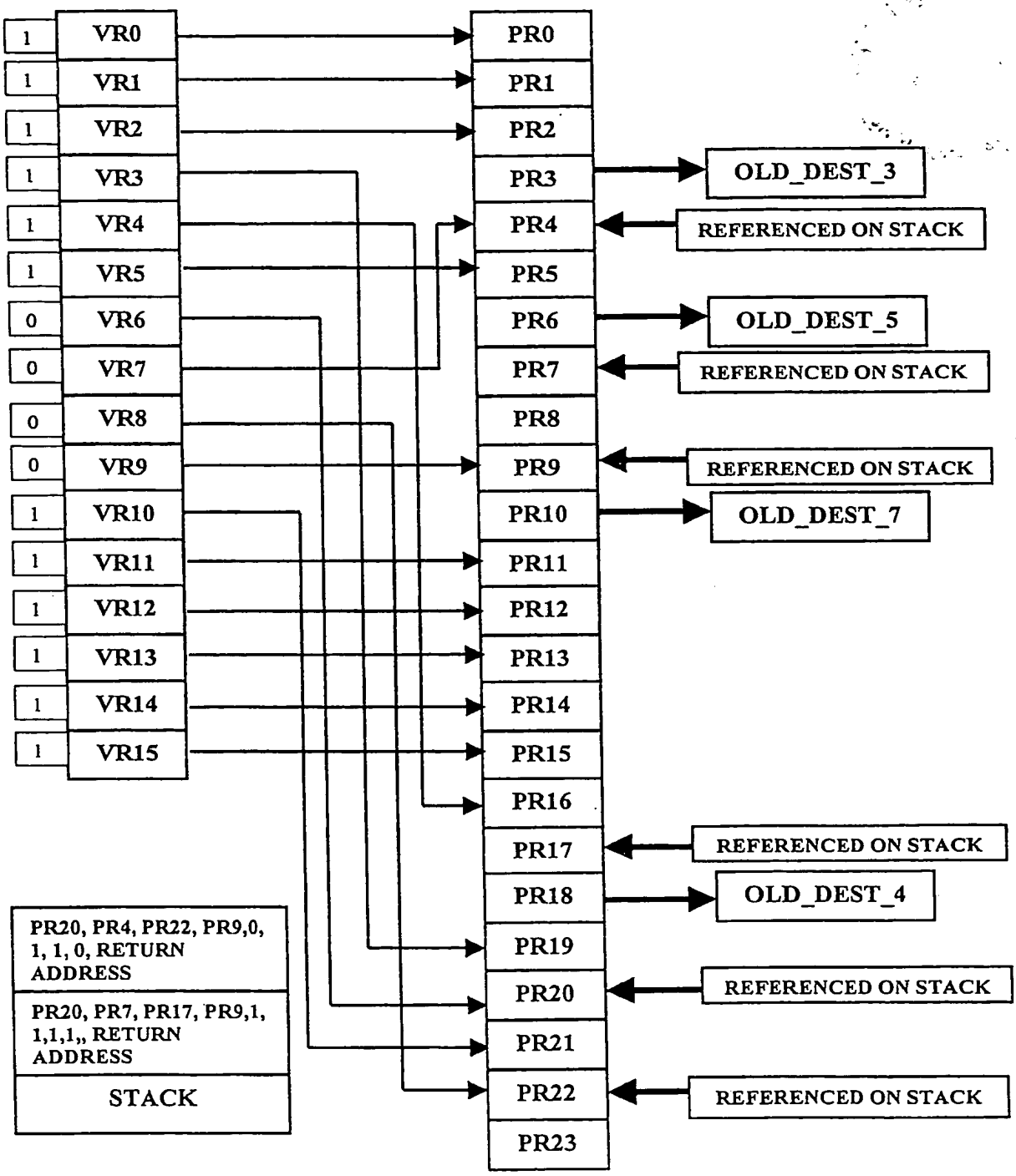
CLOCK 5: DECODE STAGE
INSTRUCTIONS 7 & 8 PHYSICAL REGISTER STATE

FIG. 35



INSTR. 9: MUL VR8, VR1, VR7 **maps to** MUL PR22, PR1, PR4
1 → DIRTY BIT FOR VR7

FIG. 36



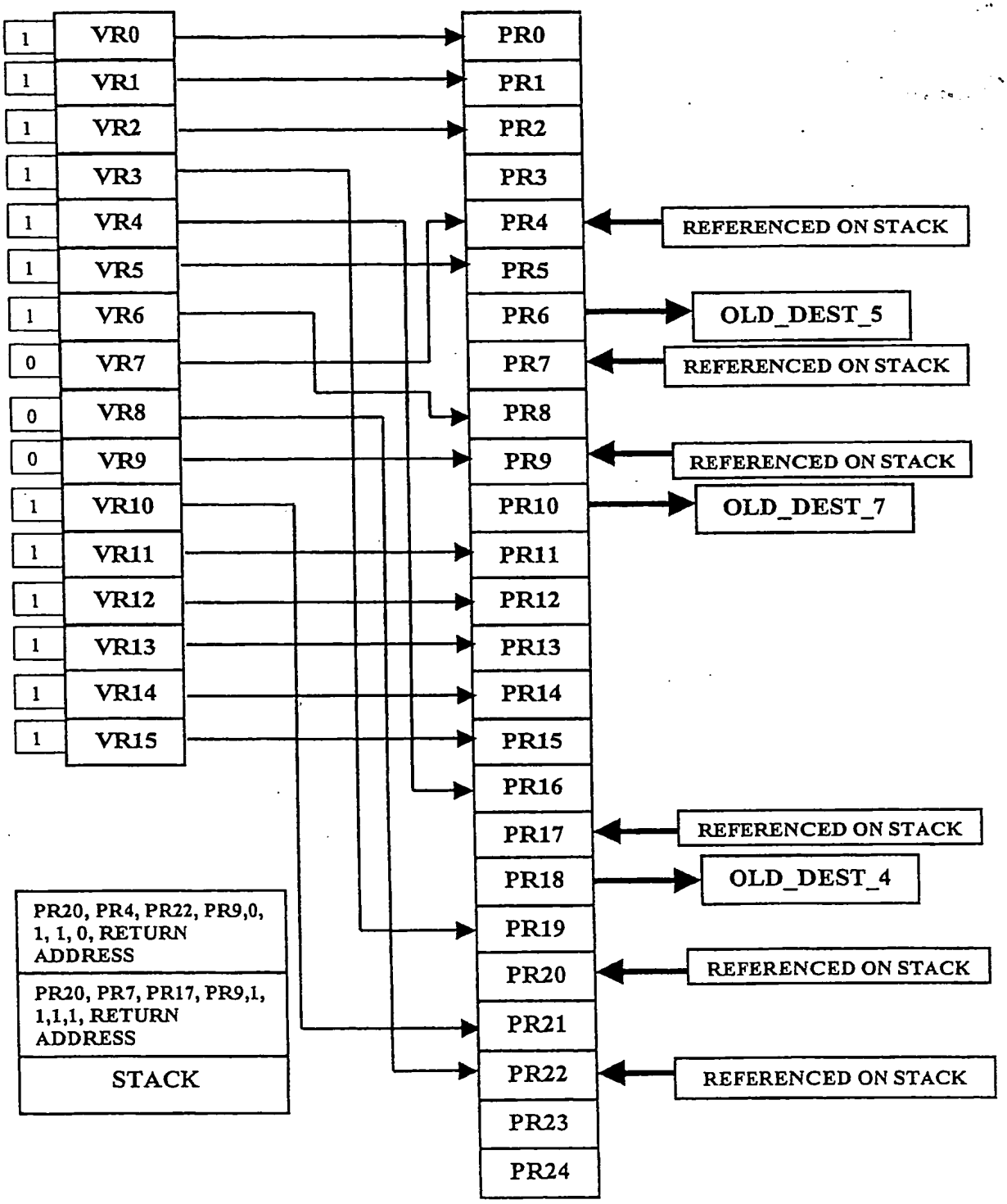
INSTR. 10: CALL B **action** PUSH PR20, PR4, PR22, PR9, 0, 1, 1, 0, RETURN ADDRESS, 0000 → DIRTY BITS FOR VR6-9, transfer to B

FIG. 37

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	1	-	-	-	INSTRUCTION 3 RETIRED
4	0	0	-	7	WAITING FOR INSTRUCTION 9 TO EXECUTE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	1	-	-	-	UNALLOCATED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	1	130	6	INSTRUCTION 5 EXECUTED
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

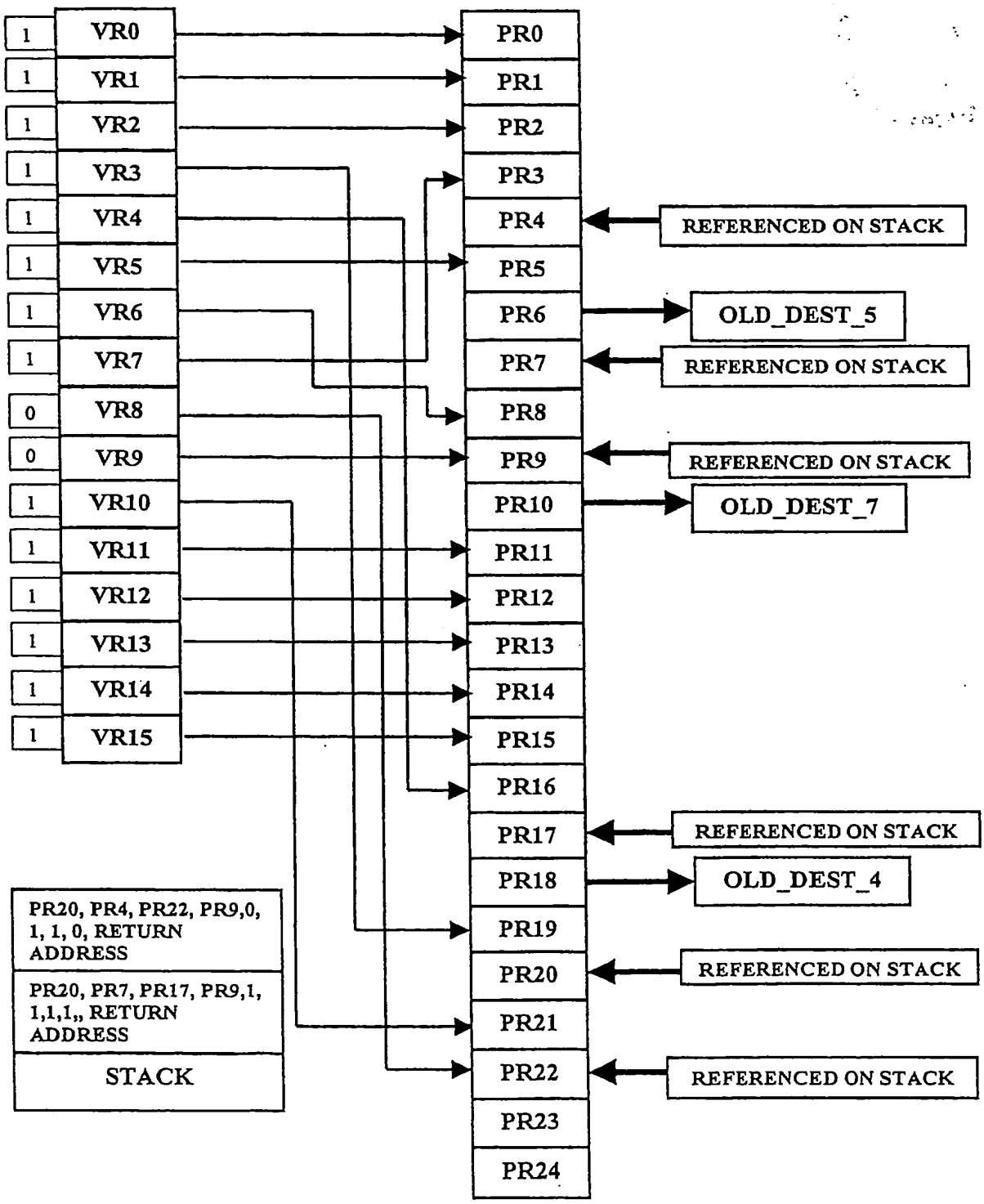
CLOCK 6: DECODE STAGE
INSTRUCTIONS 9 & 10 PHYSICAL REGISTER STATE

FIG. 38



INSTR. 11: ADD VR1, VR2, VR6 **maps to** ADD PR1, PR2, PR8
1 → DIRTY BIT FOR VR6

FIG. 39



INSTR. 12: ADD VR3, VR7, VR7 maps to ADD PR19, PR4, PR3
1 → DIRTY BIT FOR VR7

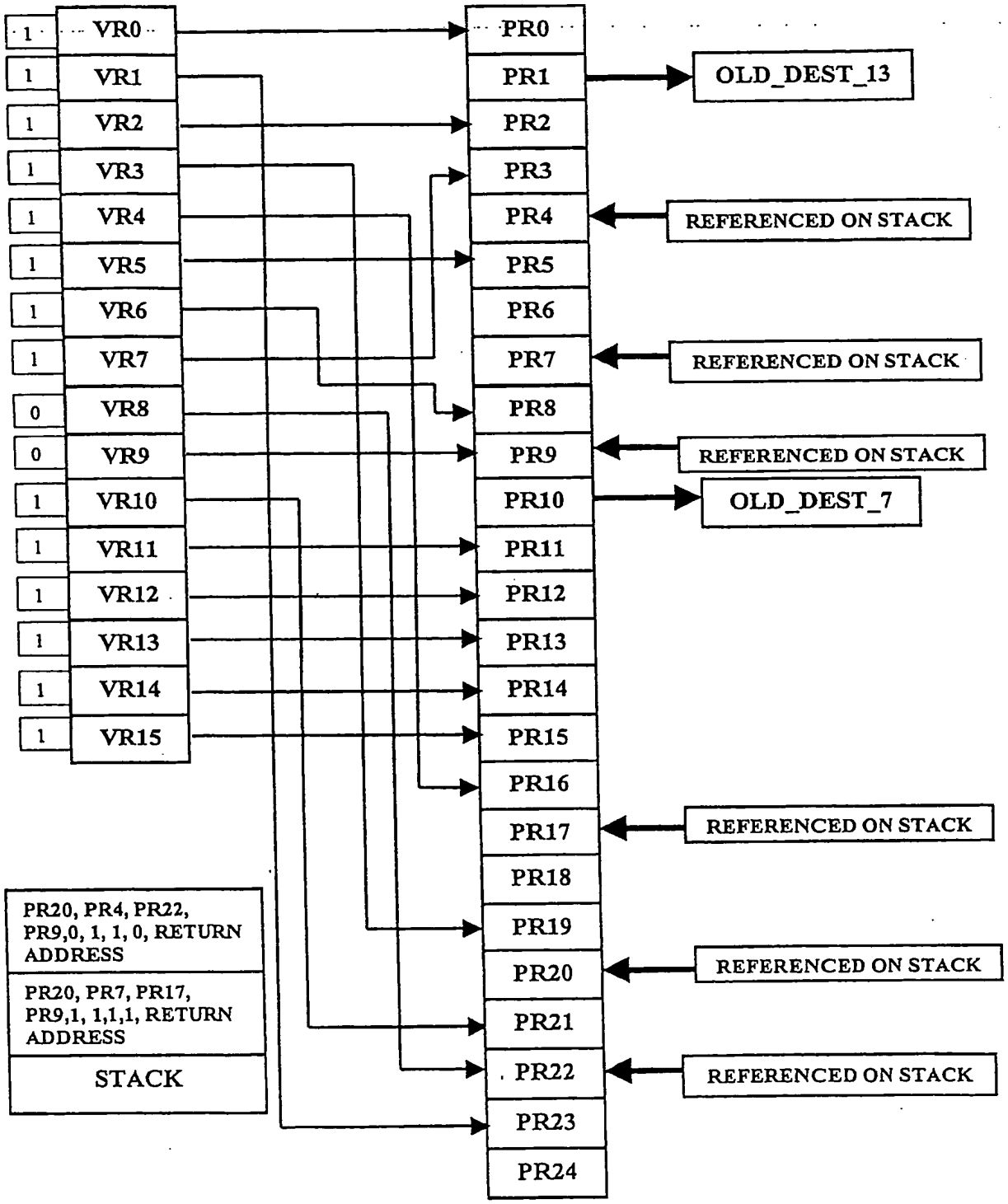
FIG. 40

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	EXAMPLE INITIALIZATION
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	7	WAITING FOR INSTRUCTION 12 TO EXECUTE
4	0	0	-	-	WAIT FOR INS. 9 TO EXECUTE, REF. SAVED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	0	0	-	6	WAITING FOR INSTRUCTION 11 TO EXECUTE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	0	1	2	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	-	REFERENCE PREVIOUSLY SAVED ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 7: DECODE STAGE

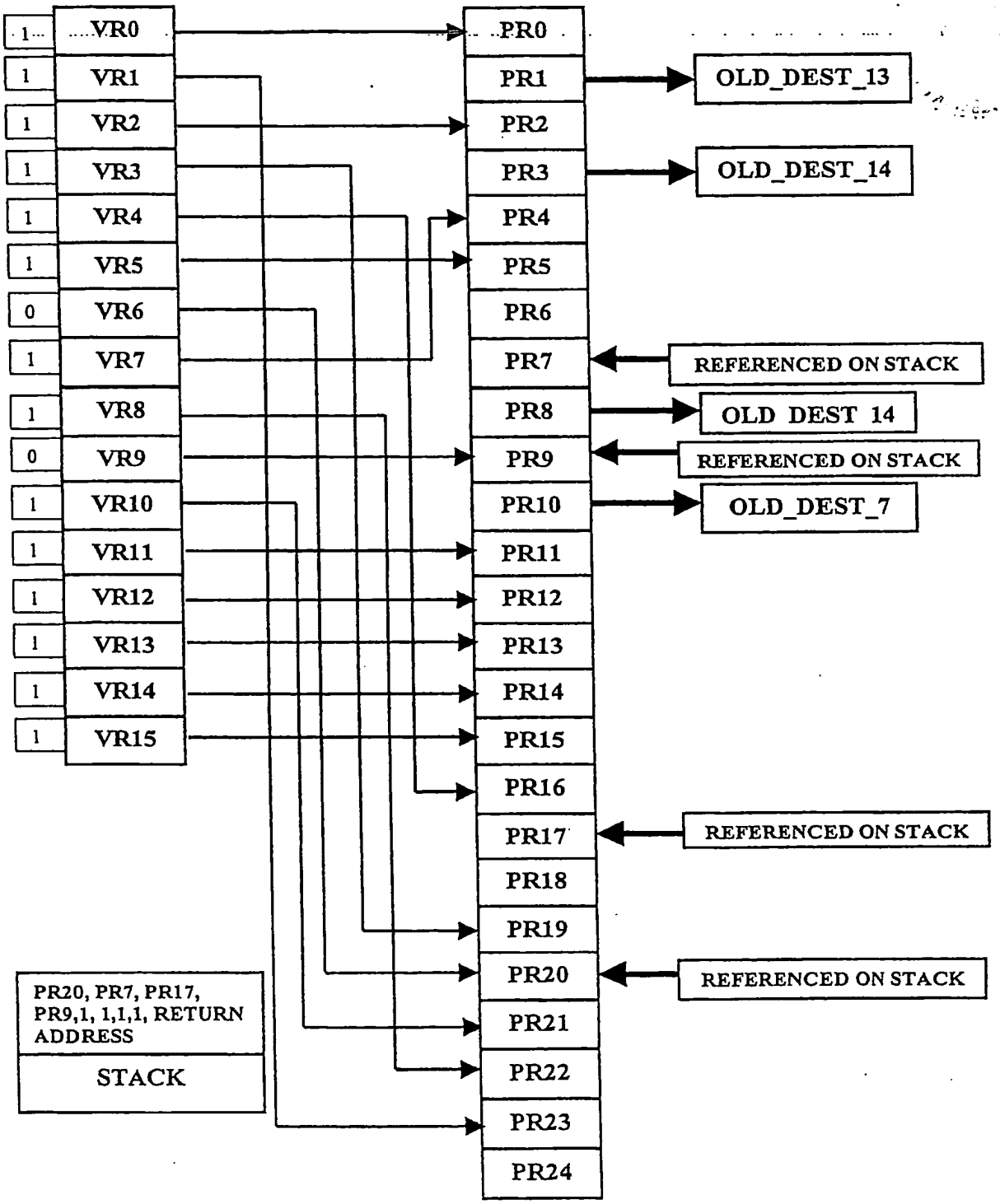
INSTRUCTIONS 11 & 12 PHYSICAL REGISTER STATE

FIG. 41



INSTR. 13: MUL VR6, VR7, VR1 **maps to** MUL PR8, PR3, PR23
PR1 → OLD_DEST_13

FIG. 42



INSTR. 14: RET maps to POP PR20, PR4, PR22, PR9 → VR6-9, 0110 → VR6-9'S DIRTY BITS,

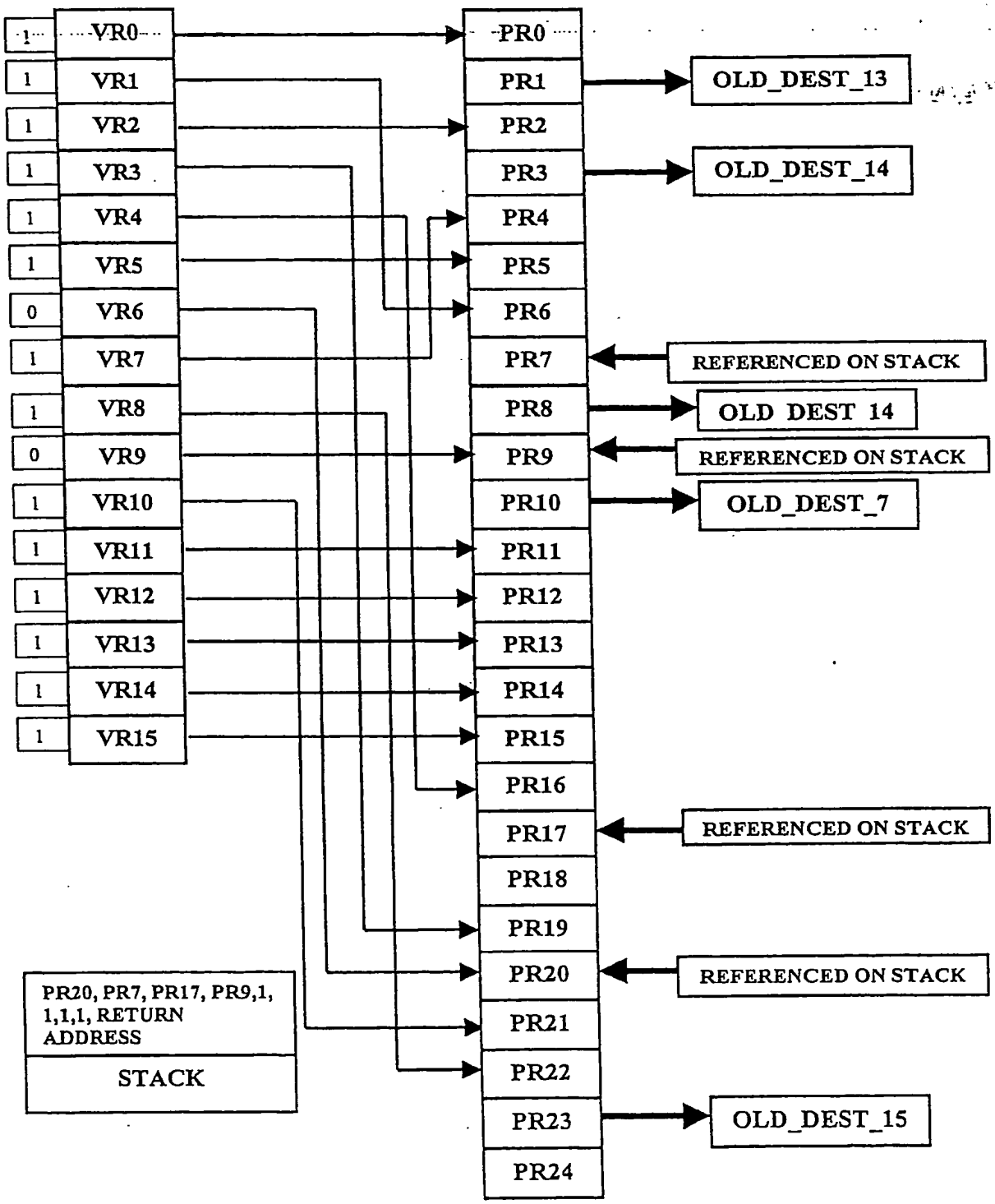
RETURN FROM SUBR. B, PR3 & PR8 → OLD_DEST_14

FIG. 43

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	7	WAIT FOR INS. 9 EXEC., VR7 REF. RESTORED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 5 RETIRED
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INSTRUCTION 2 EXECUTED
18	1	-	-	-	INSTRUCTION 4 RETIRED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	0	0	-	1	WAITING FOR INSTRUCTION 13 TO EXECUTE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

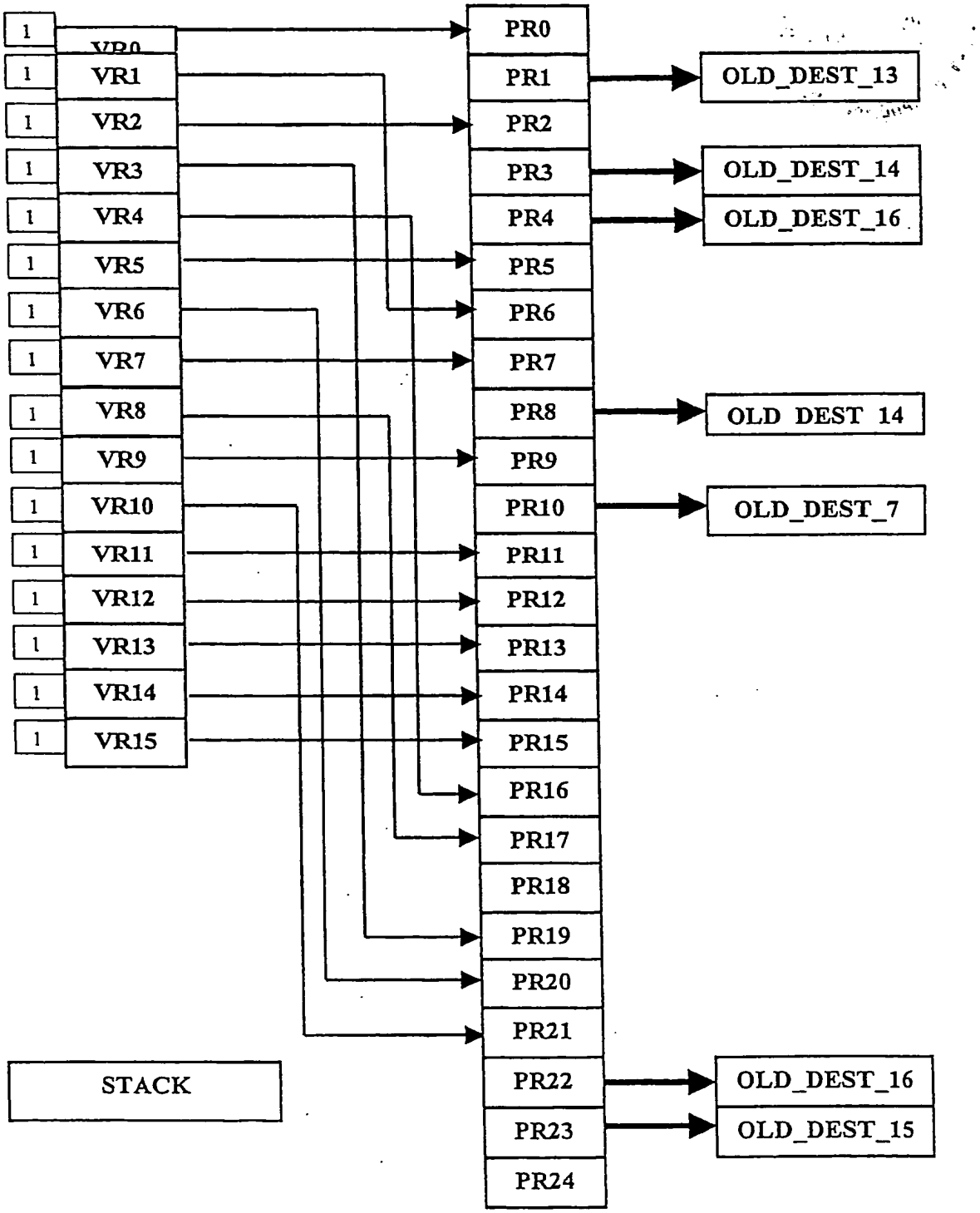
CLOCK 8: DECODE STAGE
INSTRUCTIONS 13 & 14 PHYSICAL REGISTER STATE

FIG. 44



INSTR. 15: ADD VR8, VR7, VR1 **maps to** ADD PR22, PR4, PR6
PR23 → OLD_DEST_15

FIG. 45



INSTR. 16: RET maps to POP PR20, PR7, PR17, PR9 → VR6-9, 1111 → VR6-9'S DIRTY BITS,

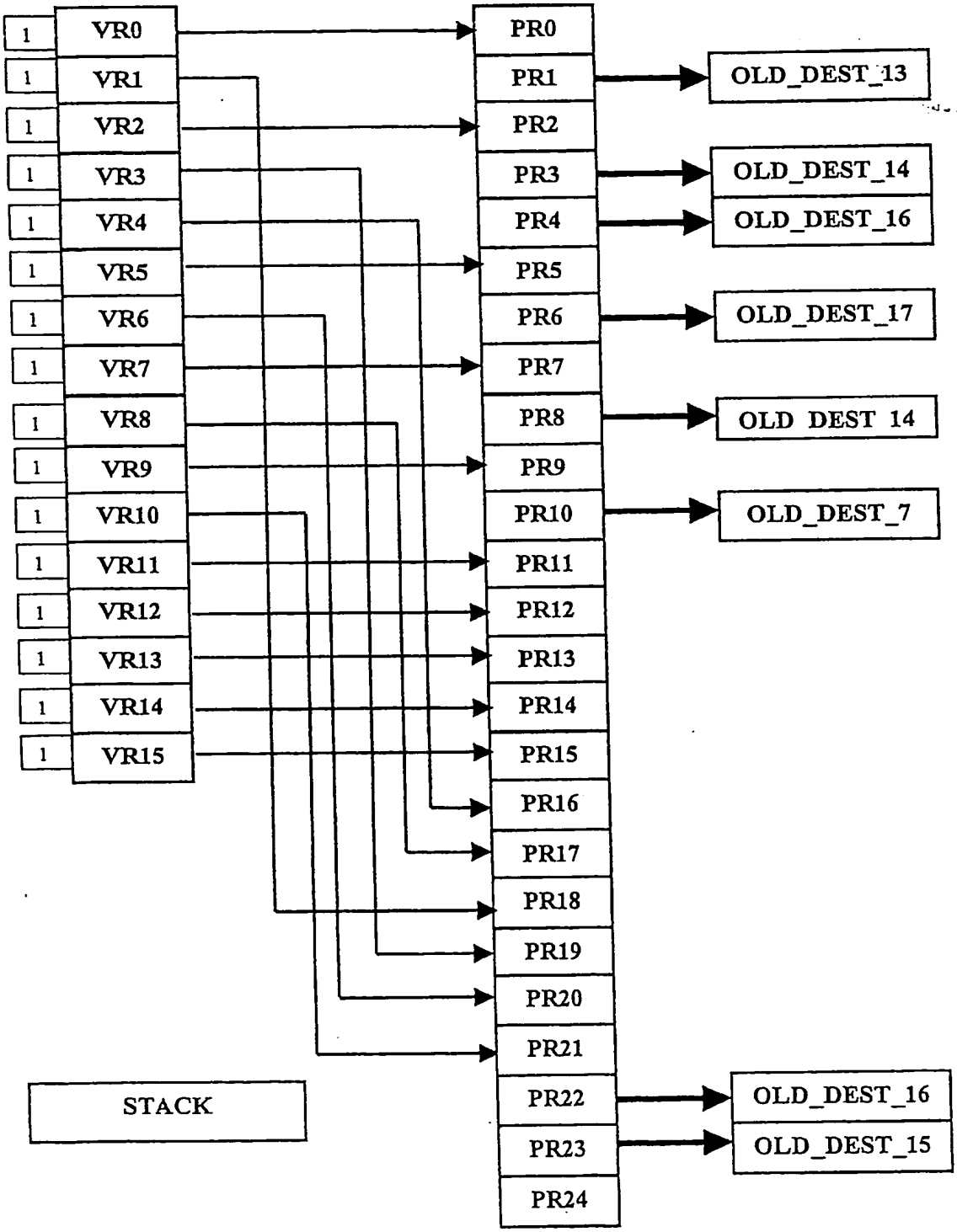
RETURN FROM SUBR. A, PR4 & PR22 → OLD_DEST_16

FIG. 46

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	2	EXAMPLE INITIALIZATION
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	-	WAIT FOR INS. 9 EXEC., INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	1	WAITING FOR INSTRUCTION 15 TO EXECUTE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	1	-	-	-	INSTRUCTION 4 RETIRED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

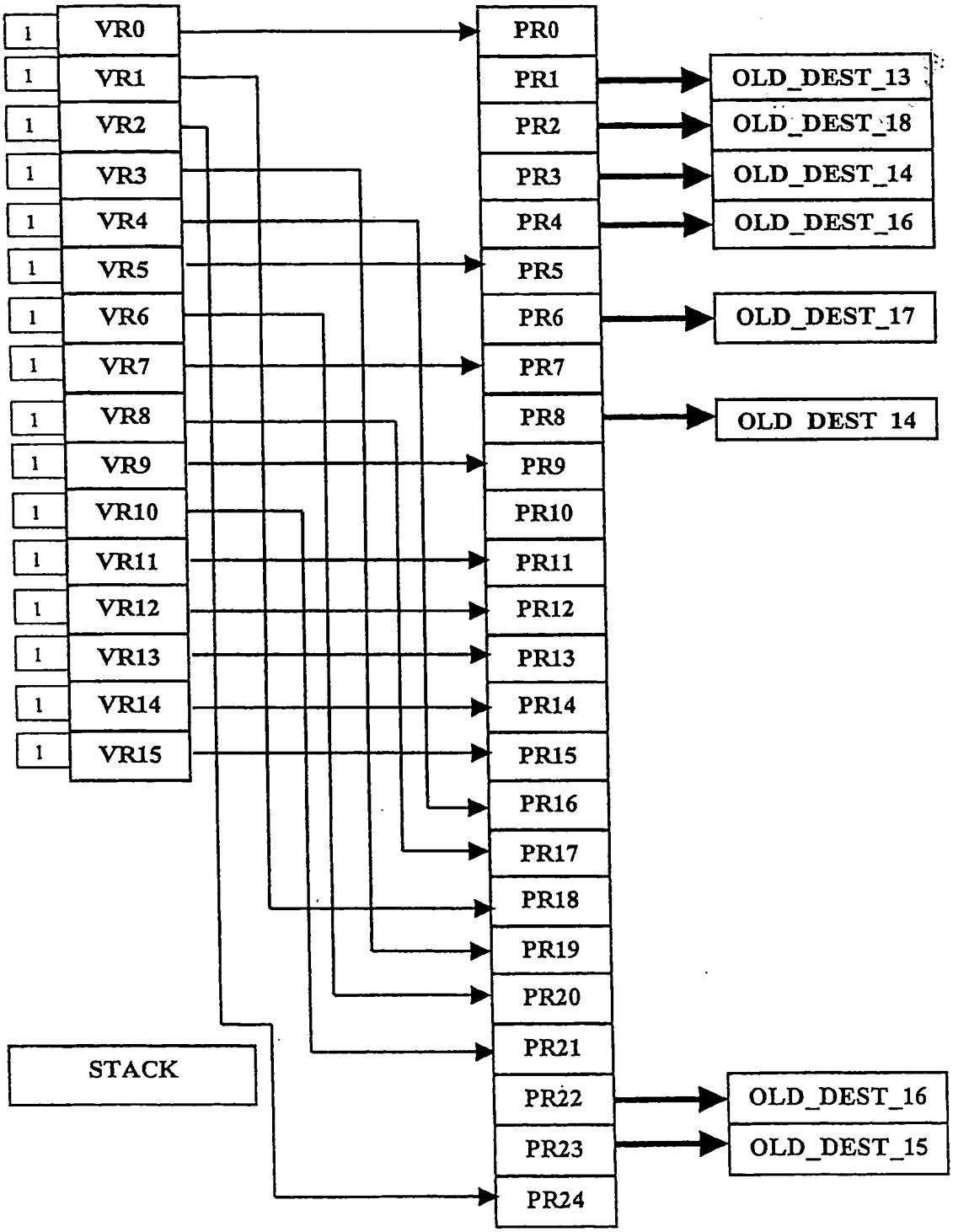
CLOCK 9: DECODE STAGE
INSTRUCTIONS 15 & 16 PHYSICAL REGISTER STATE

FIG. 47



INSTR. 17: ADD VR8, VR1, VR1 **maps to** ADD PR17, PR6, PR18
PR6 → OLD_DEST_17

FIG. 48



INSTR. 18: ADD VR8, VR2, VR2 maps to ADD PR17, PR2, PR24

PR2 → OLD_DEST_18

FIG. 49

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS.15 TO EXEC. & 17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 10: DECODE STAGE
INSTRUCTIONS 17 & 18 PHYSICAL REGISTER STATE

FIG. 50

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS.15 TO EXEC. & 17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 11: DECODE STAGE

NO CHANGE IN PHYSICAL REGISTER STATE

FIG. 51

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	0	-	1	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	0	-	2	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 12: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 52

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	-	WAIT FOR INS. 13 TO EXEC. & 15 TO RETIRE
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 13: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 53

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	WAITING FOR INSTRUCTION 13 TO RETIRE
2	0	1	7	-	WAIT FOR INSTRUCTION 18 TO RETIRE
3	0	1	-13	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	-25	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	-30	-	WAIT FOR INS.17 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	12	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	0	1	-5	-	WAIT FOR INS. 16 TO RETIRE
23	0	1	-156	-	WAIT FOR INS. 15 TO RETIRE
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 14: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 54

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	1	-	-	-	INSTRUCTION 13 RETIRED
2	1	-	-	-	INSTRUCTION 18 RETIRED
3	1	-	-	-	INSTRUCTION 14 RETIRED
4	1	-	-	-	INSTRUCTION 16 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 17 RETIRED
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	1	-	-	-	INSTRUCTION. 14 RETIRED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	10	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	VR8 REFERENCE RESTORED FROM STACK
18	0	1	-134	1	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	130	6	VR6 REFERENCE RESTORED FROM STACK
21	0	1	142	10	INSTRUCTION 7 EXECUTED
22	1	-	-	-	INSTRUCTION 16 RETIRED
23	1	0	-	-	INSTRUCTION 15 RETIRED
24	0	1	-8	2	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 15: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 55

```
A:      ADD VR6, VR3, VR10      Subroutine uses Arguments VR1 and VR2
        SUB VR2, VR3, VR8
        MUL VR8, VR1, VR7
        CALL B, 2, 8            ; Bind Arg2  to new Arg1 and bind VR8 to new Arg2
        ADD VR8, VR7, VR1
        RET                     ; Restore previous argument bindings
B:      ADD VR1, VR2, VR6       ; Subroutine uses Arguments VR1 and VR2
        ADD VR3, VR7, VR7
        MUL VR6, VR7, VR1
        RET                     ; Restore previous argument bindings
```

start of example execution

```
C:      □
        □
        □
        ADD VR0, VR0, VR4
        LIM VR8, #22
        SUB VR3, VR0, VR3
        ADD VR4, VR3, VR3
        MUL VR4, VR5, VR6
        CALL A, 6,8             ; Bind VR6 to new Arg1 and bind VR8 to new Arg2
        ADD VR8, VR0, VR0
        ADD VR8, VR6, VR6
        □
        □
        □
```

end of example execution

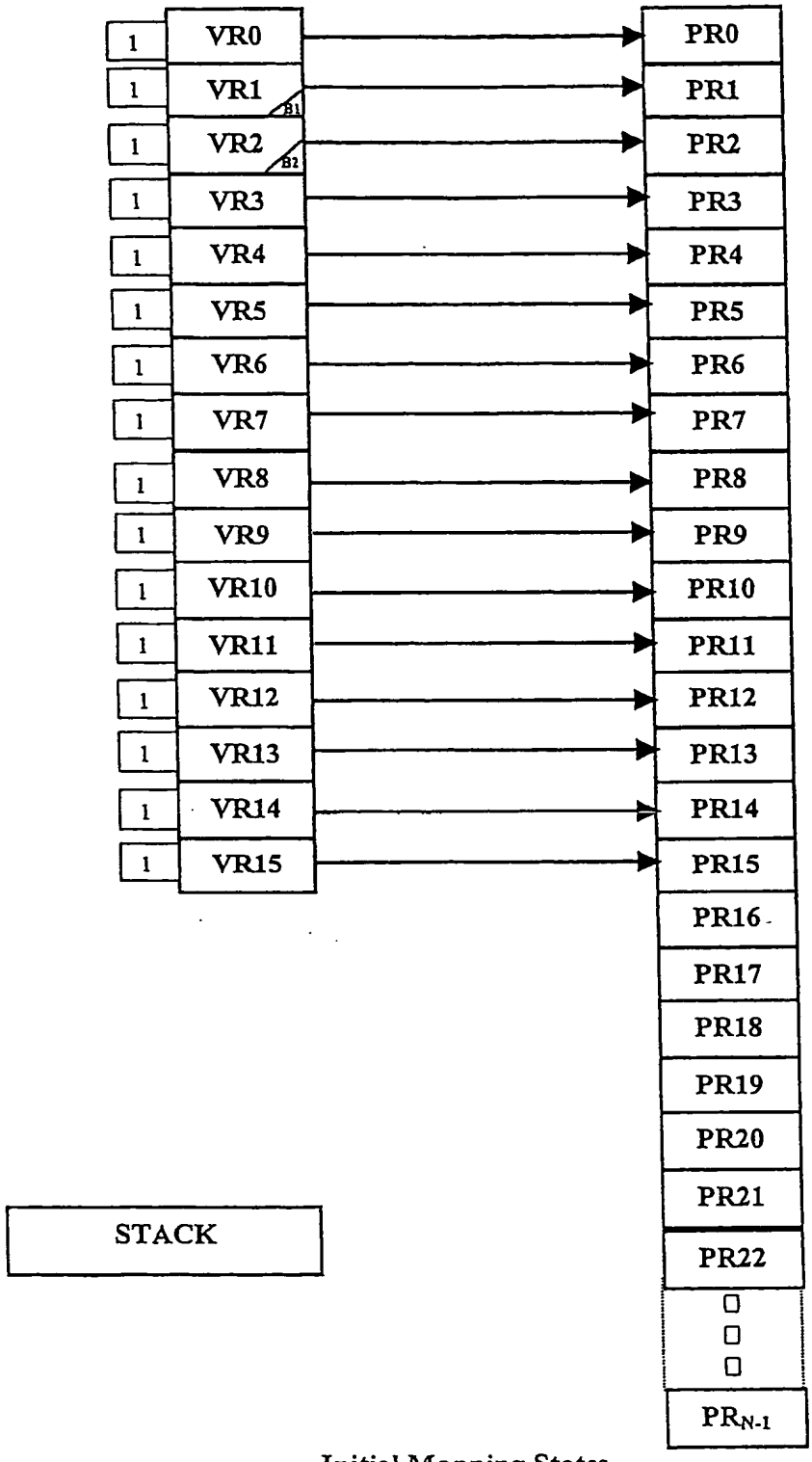
EXAMPLE PROGRAM

FIG. 56

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	DESCRIPTION
0	0	1	3	EXAMPLE INITIALIZATION
1	0	1	5	EXAMPLE INITIALIZATION
2	0	1	7	EXAMPLE INITIALIZATION
3	0	1	9	EXAMPLE INITIALIZATION
4	0	1	11	EXAMPLE INITIALIZATION
5	0	1	13	EXAMPLE INITIALIZATION
6	0	1	15	EXAMPLE INITIALIZATION
7	0	1	17	EXAMPLE INITIALIZATION
8	0	1	19	EXAMPLE INITIALIZATION
9	0	1	21	EXAMPLE INITIALIZATION
10	0	1	23	EXAMPLE INITIALIZATION
11	0	1	25	EXAMPLE INITIALIZATION
12	0	1	27	EXAMPLE INITIALIZATION
13	0	1	29	EXAMPLE INITIALIZATION
14	0	1	31	EXAMPLE INITIALIZATION
15	0	1	33	EXAMPLE INITIALIZATION
16	1	-	-	UNALLOCATED
17	1	-	-	UNALLOCATED
18	1	-	-	UNALLOCATED
19	1	-	-	UNALLOCATED
20	1	-	-	UNALLOCATED
21	1	-	-	UNALLOCATED
22	1	-	-	UNALLOCATED
23	1	-	-	UNALLOCATED
24	1	-	-	UNALLOCATED
ETC.	1	-	-	UNALLOCATED

CLOCK 1: DECODE STAGE
INITIAL PHYSICAL REGISTER STATE

FIG. 57



Initial Mapping States

FIG. 58

INSTRUCTION #	INSTRUCTION	DESCRIPTION	EFFECT OF INSTRUCTION
1	ADD VR0, VR0, VR4	VR0 + VR0 → VR4	(3 + 3) → 6 → VR4
2	LIM VR8, #22	22 → VR8	22_{10} → VR8
3	SUB VR3, VR0, VR3	VR3 – VR0 → VR3	(9 – 3) → 6 → VR3
4	ADD VR4, VR3, VR3	VR4 + VR3 → VR3	(6 + 6) → 12 → VR3
5	MUL VR4, VR5, VR6	VR4 * VR5 → VR6	(6 * 13) → 78 → VR6
6	CALL A, VR6, VR8	CALL subroutine A(Arg1, Arg2)	Arg1 □ VR6, Arg2 □ VR8, VR6—VR9 scratch registers; VR1 □ Arg1 , VR2 □ Arg2.
7	ADD VR1, VR3, VR10	VR1 + VR3 → VR10	(78 + 12) → 90 → VR10 (Uses C program's VR6 as source)
8	SUB VR2, VR3, VR8	VR2 –VR3 → VR8	(22 – 12) → 10 → VR8 (Uses C programs's VR8 as source)
9	MUL VR8, VR1, VR7	VR8 * VR1 → VR7	(10 * 78) → 780 → VR7 (use VR7 as scratch register)
10	CALL B, VR2, VR8	CALL subroutine B(Arg1, Arg2)	Arg1 □ A's Arg2, Arg2 □ VR8, VR6—VR9 scratch registers; VR1 □ Arg1 , VR2 □ Arg2
11	ADD VR1, VR2, VR6	VR1 + VR2 → VR6	(22 + 10) → 32 → VR6 (Uses C program's VR8 as source, A program's VR8 as source, and uses VR6 as scratch register)
12	ADD VR3, VR7, VR7	VR3 + VR7 → VR7	(12 + 780) → 792 → VR7 (use VR7 as scratch register)
13	MUL VR6, VR7, VR1	VR6 * VR7 → VR1	(32 * 792) → 25344 → VR1 (Uses C program's VR8 as destination)
14	RET	RETURN	restore value of 78 to VR6 , 780 to VR7, VR1 link to C's VR6, and VR2 link to C's VR8.
15	ADD VR8, VR7, VR1	VR8 + VR7 → VR1	(10 + 780) → 790 → VR1 (Uses C program's VR6 as destination)
16	RET	RETURN	restore value of 790 to VR6, 17 to VR7, 25344 to VR8, and VR1 and VR2 links to VRs in Program that Called C.
17	ADD VR8, VR0, VR0	VR8 + VR0 → VR0	(25344 + 3) → 25347 → VR0
18	ADD VR8, VR6, VR6	VR8 + VR6 → VR6	(25344 + 790) → 26134 → VR6

EXAMPLE INSTRUCTION FLOW

FIG. 59

INSTRUCTION NUMBER	VIRTUAL REGISTER NUMBER: / INSTRUCTION / INITIAL VALUE:	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33
1	ADD VR0, VR0, VR4	3	5	7	9	6	13	15	17	19	21	23	25	27	29	31	33
2	LIM VR8, #22	3	5	7	9	6	13	15	17	22	21	23	25	27	29	31	33
3	SUB VR3, VR0, VR3	3	5	7	6	6	13	15	17	22	21	23	25	27	29	31	33
4	ADD VR4, VR3, VR3	3	5	7	12	6	13	15	17	22	21	23	25	27	29	31	33
5	MUL VR4, VR5, VR6	3	5	7	12	6	13	78	17	22	21	23	25	27	29	31	33
6	CALL A, VR6, VR8	3	78	22	12	6	13	78	17	22	21	23	25	27	29	31	33
7	ADD VR1, VR3, VR10	3	78	22	12	6	13	78	17	22	21	90	25	27	29	31	33
8	SUB VR2, VR3, VR8	3	78	22	12	6	13	78	17	10	21	90	25	27	29	31	33
9	MUL VR8, VR1, VR7	3	78	22	12	6	13	78	780	10	21	90	25	27	29	31	33
10	CALL B, VR2, VR8	3	22	10	12	6	13	78	780	10	21	90	25	27	29	31	33
11	ADD VR1, VR2, VR6	3	22	10	12	6	13	32	780	10	21	90	25	27	29	31	33
12	ADD VR3, VR7, VR7	3	22	10	12	6	13	32	792	10	21	90	25	27	29	31	33
13	MUL VR6, VR7, VR1	3	25344	10	12	6	13	32	792	10	21	90	25	27	29	31	33
14	RET	3	78	22	12	6	13	78	780	10	21	90	25	27	29	31	33
15	ADD VR8, VR7, VR1	3	790	22	12	6	13	78	780	10	21	90	25	27	29	31	33
16	RET	3	5	7	12	6	13	790	17	25344	21	90	25	27	29	31	33
17	ADD VR8, VR0, VR0	25347	5	7	12	6	13	790	17	25344	21	90	25	27	29	31	33
18	ADD VR8, VR6, VR6	25347	5	7	12	6	13	26134	17	25344	21	90	25	27	29	31	33

CONTENTS OF VIRTUAL REGISTERS AS INSTRUCTIONS EXECUTE

FIG. 60

Clock 1			
Fetch instr. 1, 2.			
Clock 2			
Fetch instr. 3, 4;	Decode instr. 1, 2.		
Clock 3			
Fetch instr. 5, 6;	Decode instr. 3, 4;	Read regs. PR0 for instr. 1.	
Clock 4			
Fetch instr. 7, 8;	Decode instr. 5, 6;	Read regs. PR0, PR3 for instr. 3;	Execute instr. 1, 2 and store results in PR16, PR17 respectively. Execute instr. 6 (CALL A) including binding VR1 to VR6 and VR2 to VR8.
Clock 5			
Fetch instr. 9, 10;	Decode instr. 7, 8;	Read regs. PR5, PR16 for instr. 5;	Execute instr. 3; store result in PR18. Retire instr. 1, 2.
Clock 6			
Fetch instr. 11, 12;	Decode instr. 9, 10;	Read regs. PR16, PR18 for instr. 4;	Execute instr. 5 and store result in PR20; Execute instr. 10 (CALL B) including binding VR1 to; VR2 and VR2 to VR8. Retire instr. 3.
Clock 7			
Fetch instr. 13, 14;	Decode instr. 11, 12;		Execute instr. 4 and store result in PR19.
Clock 8			
Fetch instr. 15, 16;	Decode instr. 13, 14;	Read regs. PR17, PR19, PR20 for instr. 7, 8;	Execute instr 14(Return) including restoring bindings to that for "A".. Retire instr. 4, 5, 6.

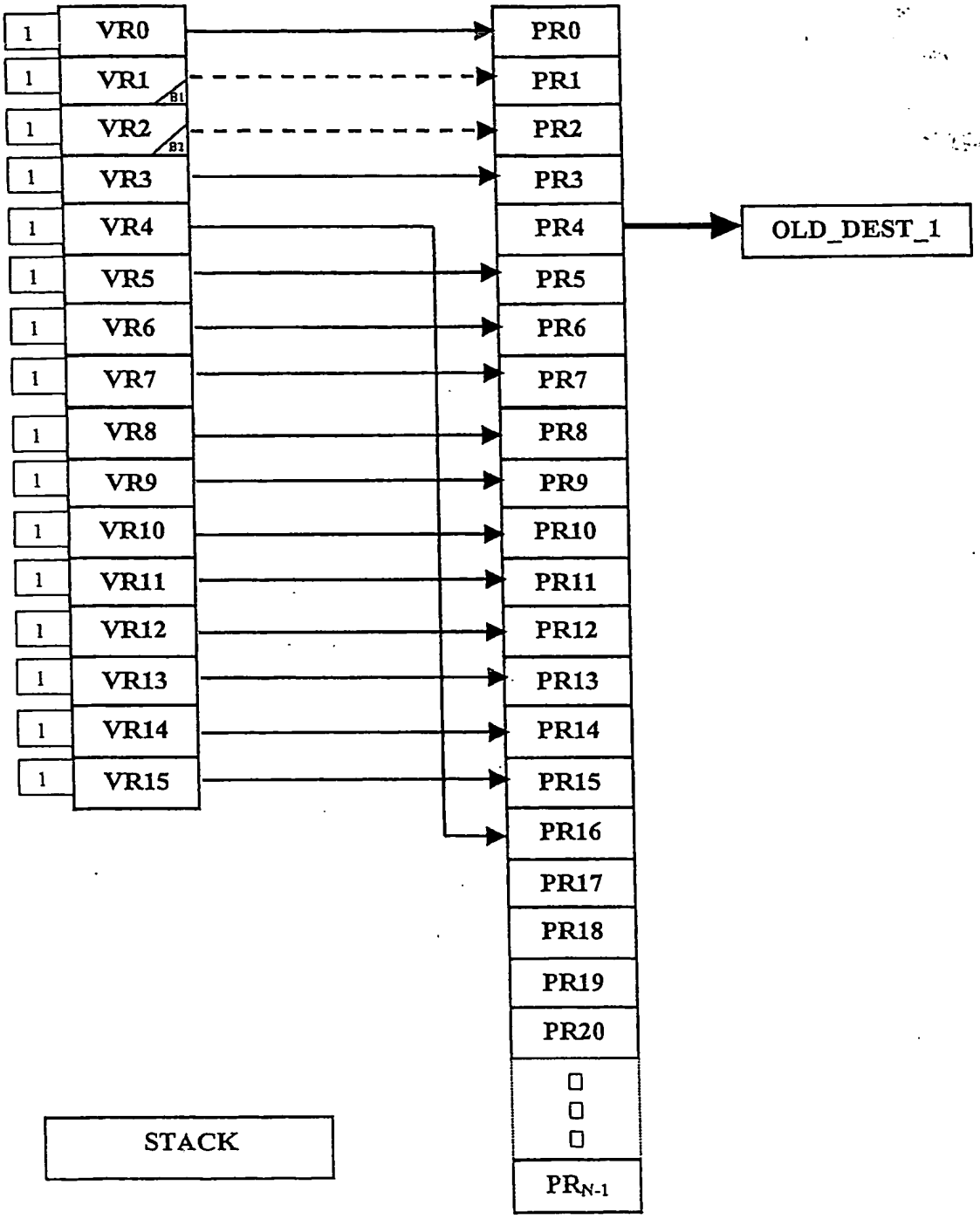
Clock by Clock Pipeline Description

FIG. 61A

Clock 9			
Fetch instr. 17, 18;	Decode instr. 15, 16;	Read regs. PR17, PR20, PR22 for instr. 9 and 11;	Execute instr. 7 and 8 and store results in PR21 and PR22 respectively. Execute instr. 16(Return) including restoring bindings to that for the "C".
Clock 10			
	Decode instr. 17, 18;		Execute instr. 9 and 11 and store results in PR4 and PR8 respectively.
Clock 11			
		Read regs. PR4, PR19, PR22 for instr. 12 and 15;	Retire instr. 9, 10, 11.
Clock 12			
		Read regs. PR0, PR6, PR23 for instr. 17 and 18;	Execute instr. 12, 15 and store results in PR3 and PR6 respectively.
Clock 13			
		Read regs. PR3, PR8 for instr. 13;	Execute instr. 17, 18 and store results in PR18 and PR24 respectively; Retire instr. 12.
Clock 14			
			Execute instr. 13 and store results in PR23.
Clock 15			
			Retire instr. 13, 14, 15, 16, 17, 18.

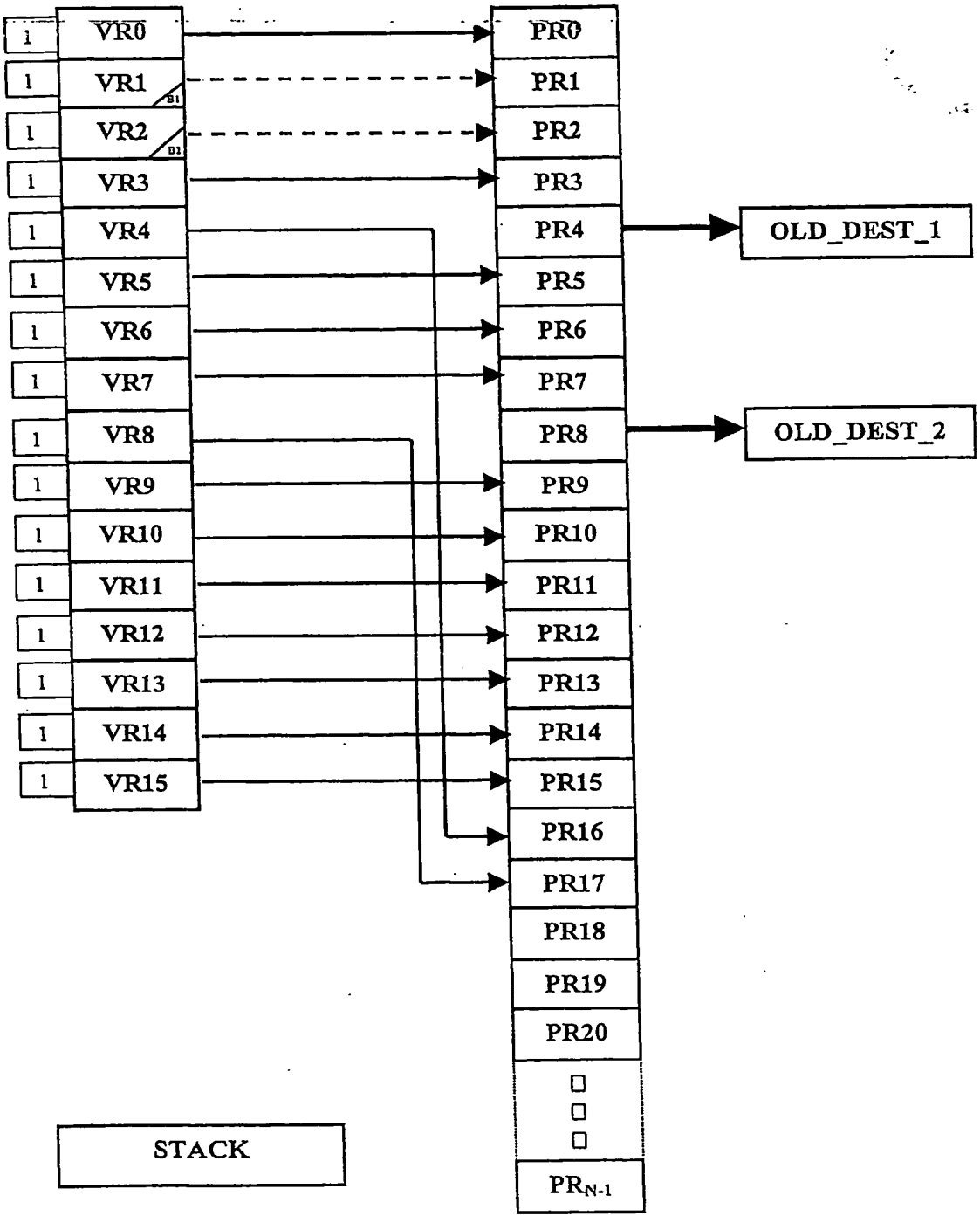
Clock by Clock Pipeline Description

FIG. 61B



INSTR. 1: ADD VR0, VR0, VR4 maps to PR0 + PR0 → PR16,
PR4 → OLD_DEST_1

FIG. 62



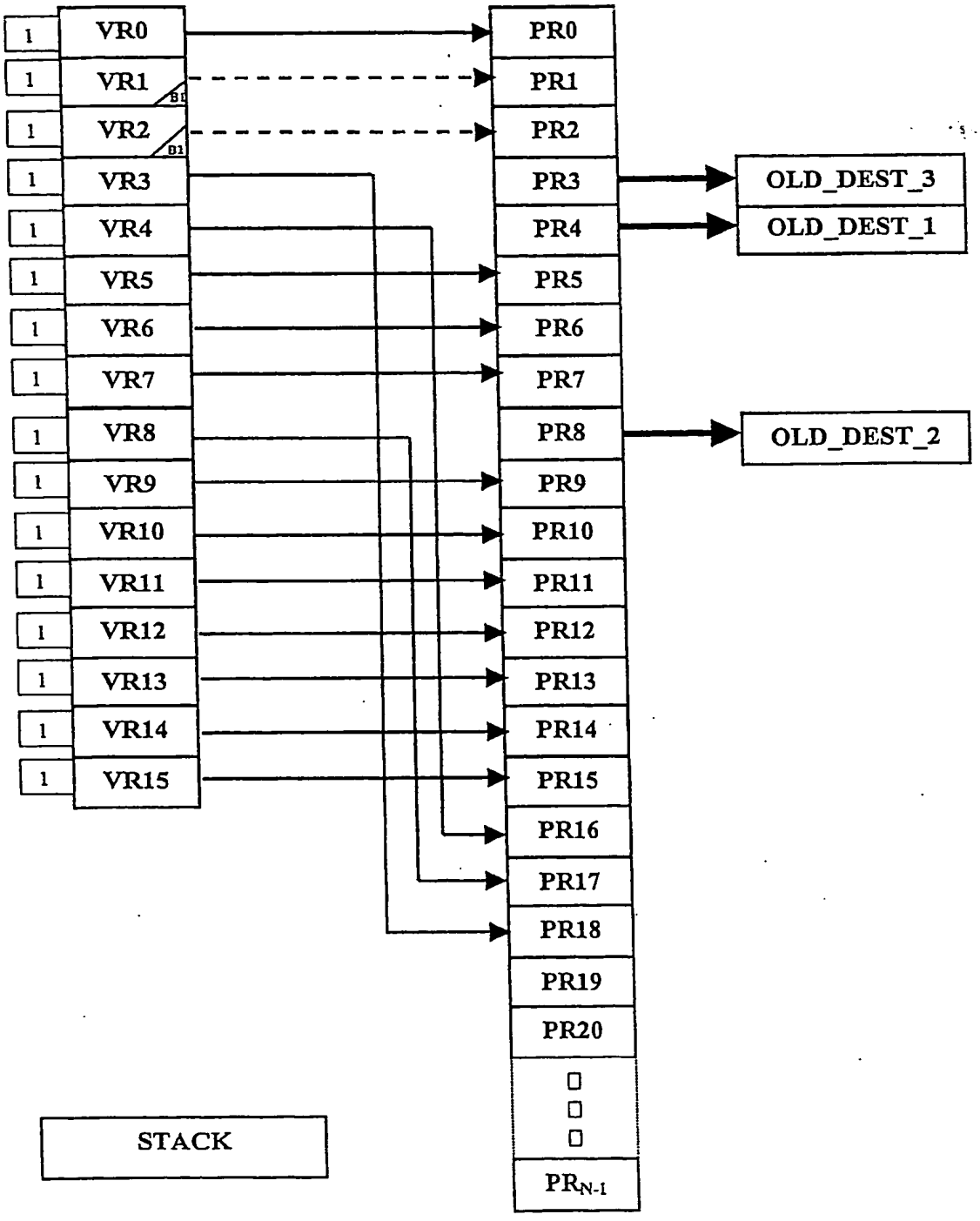
INSTR. 2: LIM VR8, #22 **maps to** LIM PR17, #22,
PR8 → OLD_DEST_2

FIG. 63

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	3	EXAMPLE INITIALIZATION
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	UNALLOCATED
19	1	-	-	-	UNALLOCATED
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

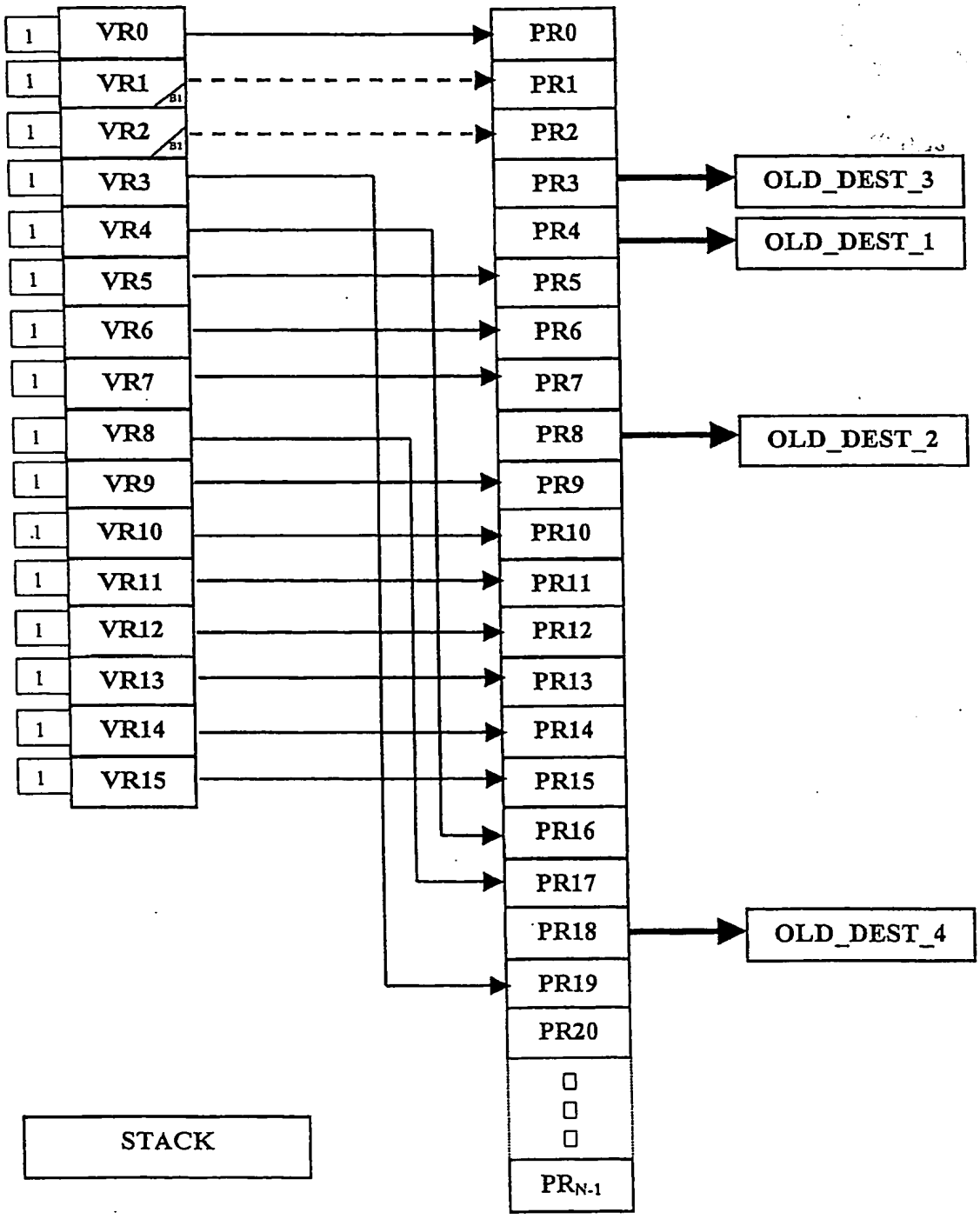
CLOCK 2: DECODE STAGE
INSTRUCTIONS 1 & 2 PHYSICAL REGISTER STATE

FIG. 64



INSTR. 3: SUB VR3, VR0, VR3 **maps to** SUB PR3, PR0, PR18,
PR3 → OLD_DEST_3

FIG. 65



INSTR. 4: ADD VR4, VR3, VR3 PR19, **maps to** ADD PR16, PR18, PR18 → OLD_DEST_4

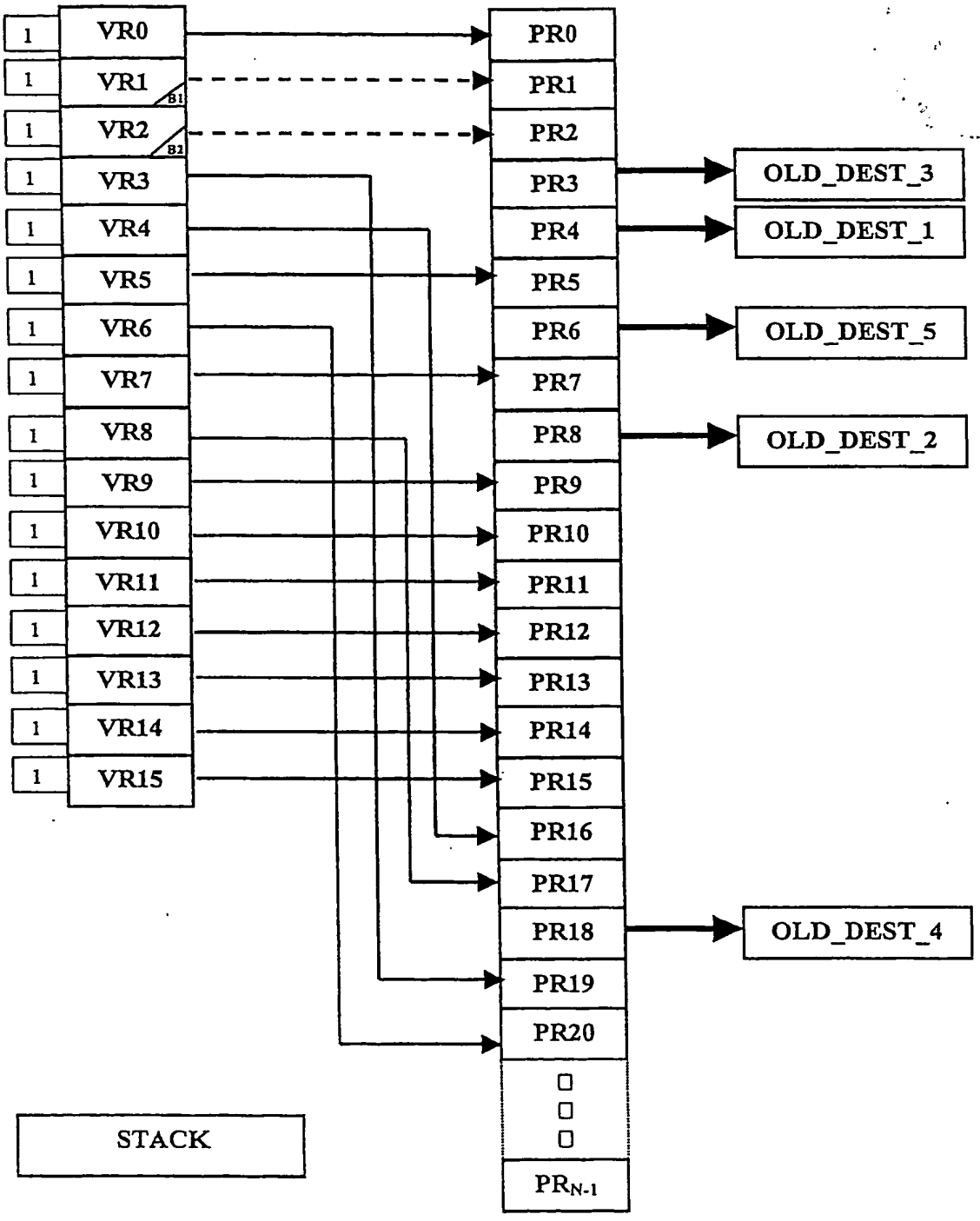
FIG. 66

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	6	EXAMPLE INITIALIZATION
7	0	1	17	7	EXAMPLE INITIALIZATION
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	0	-	4	WAITING FOR INSTRUCTION 1 TO EXECUTE
17	0	0	-	8	WAITING FOR INSTRUCTION 2 TO EXECUTE
18	1	-	-	-	WAITING FOR 3 TO EXECUTE & RETIRE
19	1	-	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	1	-	-	-	UNALLOCATED
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 3: DECODE STAGE

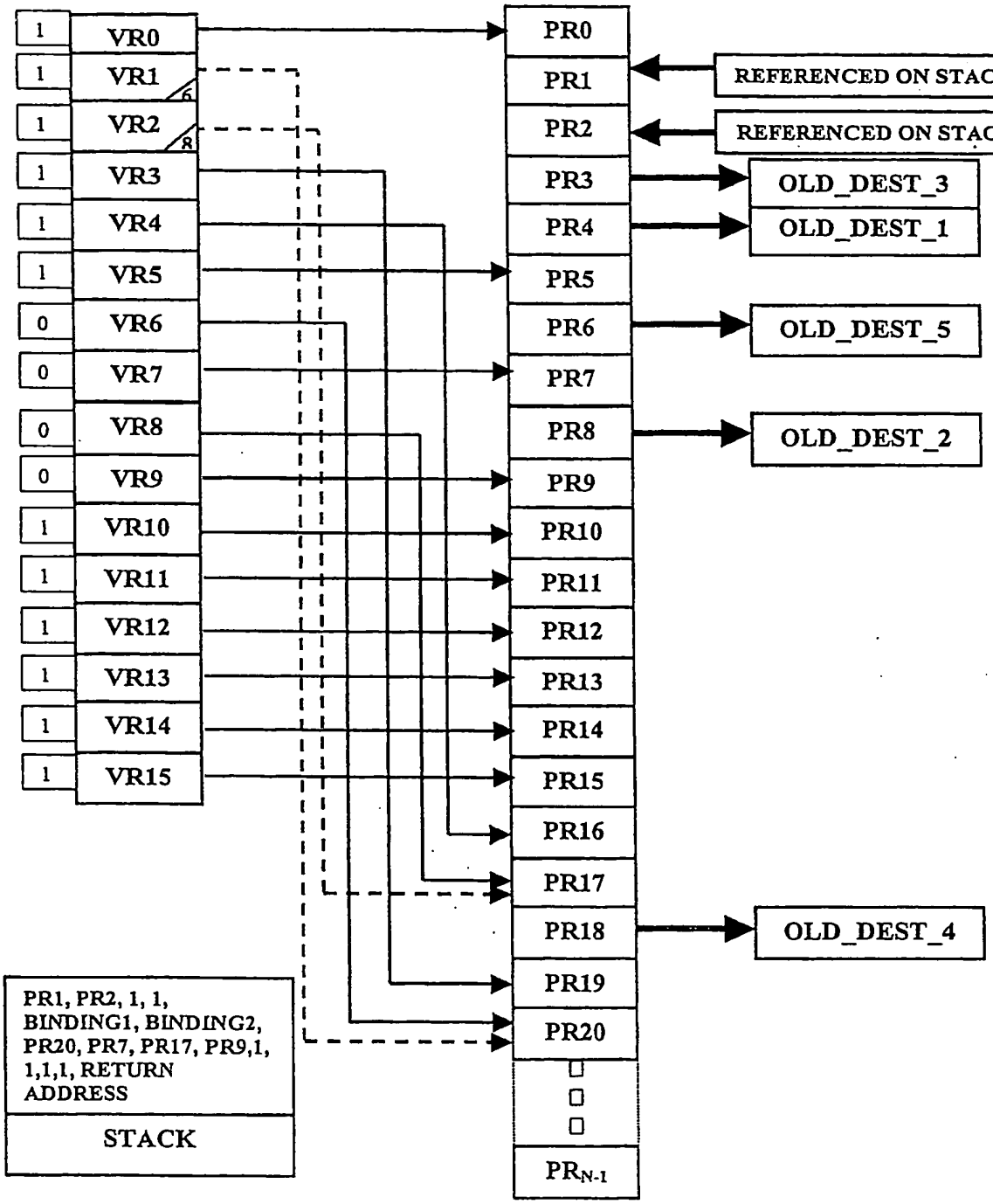
INSTRUCTIONS 3 & 4 PHYSICAL REGISTER STATE

FIG. 67



INSTR. 5: MUL VR4, VR5, VR6 **maps to** MUL PR16, PR5, PR20, PR6 → OLD_DEST_5

FIG. 68



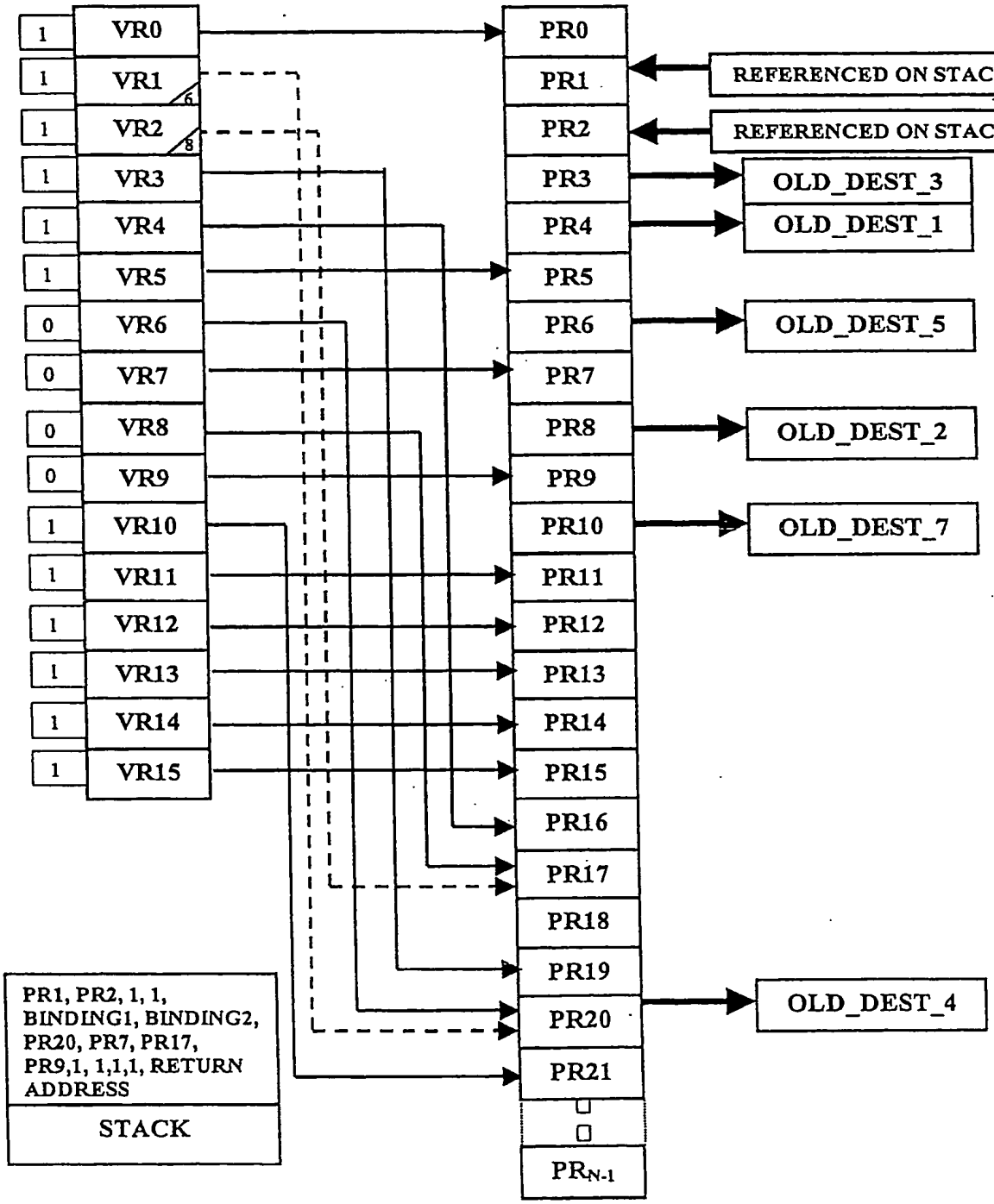
INSTR. 6: CALL A,VR6,VR8 **action** PUSH PR1, PR2, 1, 1, BINDING1, BINDING2, PR20, PR7, PR17, PR9, 1, 1, 1, 1, RETURN ADDRESS; BINDVR6_PR20, BINDVR8_PR17, DIRTY BITS FOR VR6&8 → DIRTY BITS FOR VR1&2, 0000 → DIRTY BITS FOR VR6-9, transfer to A

FIG. 69

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	0	1	11	-	WAITING FOR INSTRUCTION 1 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	REFERENCED ON STACK
8	0	1	19	-	WAITING FOR INSTRUCTION 2 TO RETIRE
9	0	1	21	9	REFERENCED ON STACK
10	0	1	23	10	EXAMPLE INITIALIZATION
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8, 2	INS. 2 EXECUTED, REFERENCED. ON STACK
18	0	0	-	-	WAITING FOR INST. 3 TO EXECUTE & RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6, 1	WAIT FOR INS. 5 TO EXEC., REF'D. ON STACK
21	1	-	-	-	UNALLOCATED
22	1	-	-	-	UNALLOCATED
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

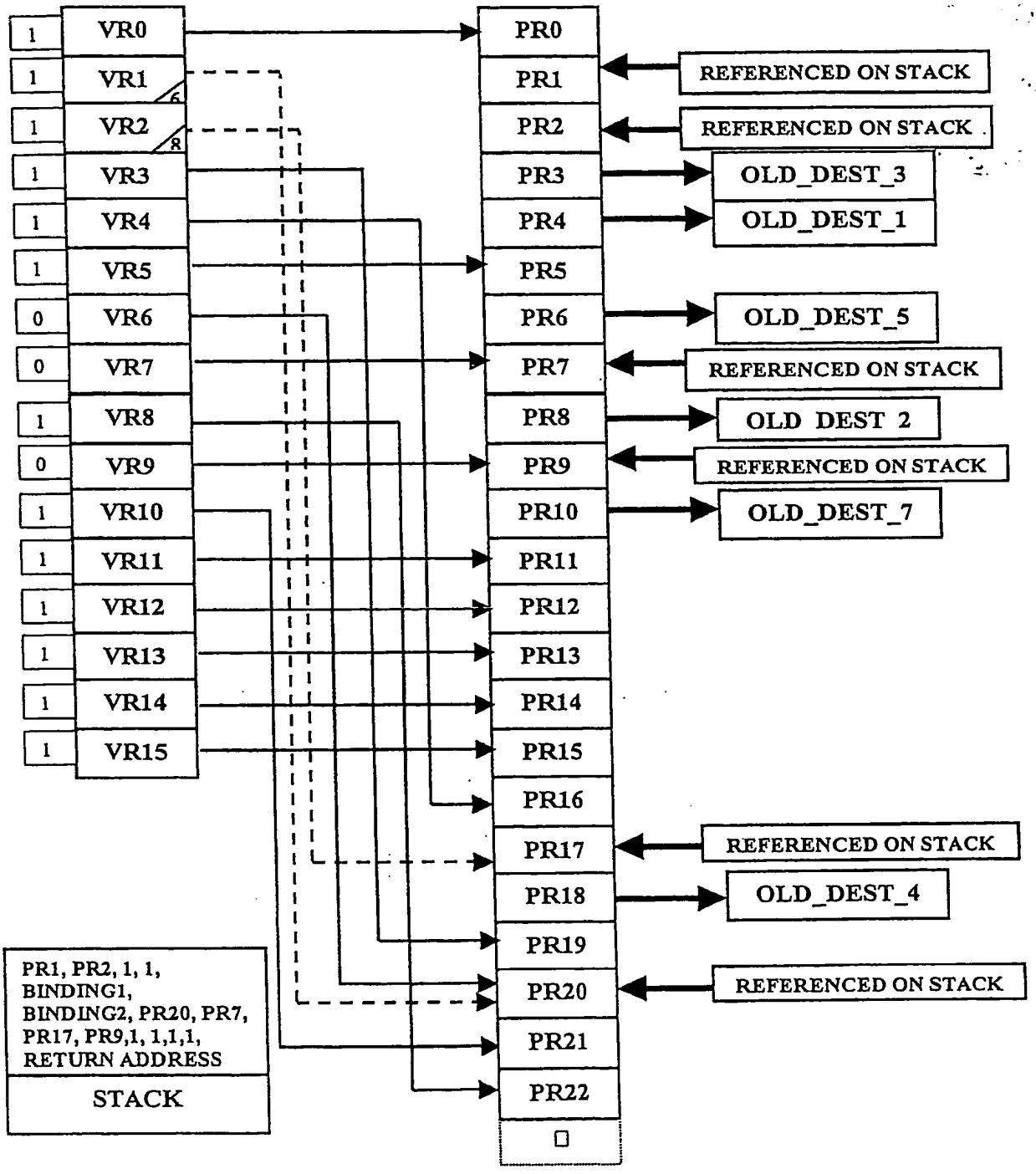
CLOCK 4: DECODE STAGE
INSTRUCTIONS 5 & 6 PHYSICAL REGISTER STATE

FIG. 70



INSTR. 7: ADD VR1, VR3, VR10 **maps to** ADD PR20, PR19, PR21, PR10 → OLD_DEST_7

FIG. 71



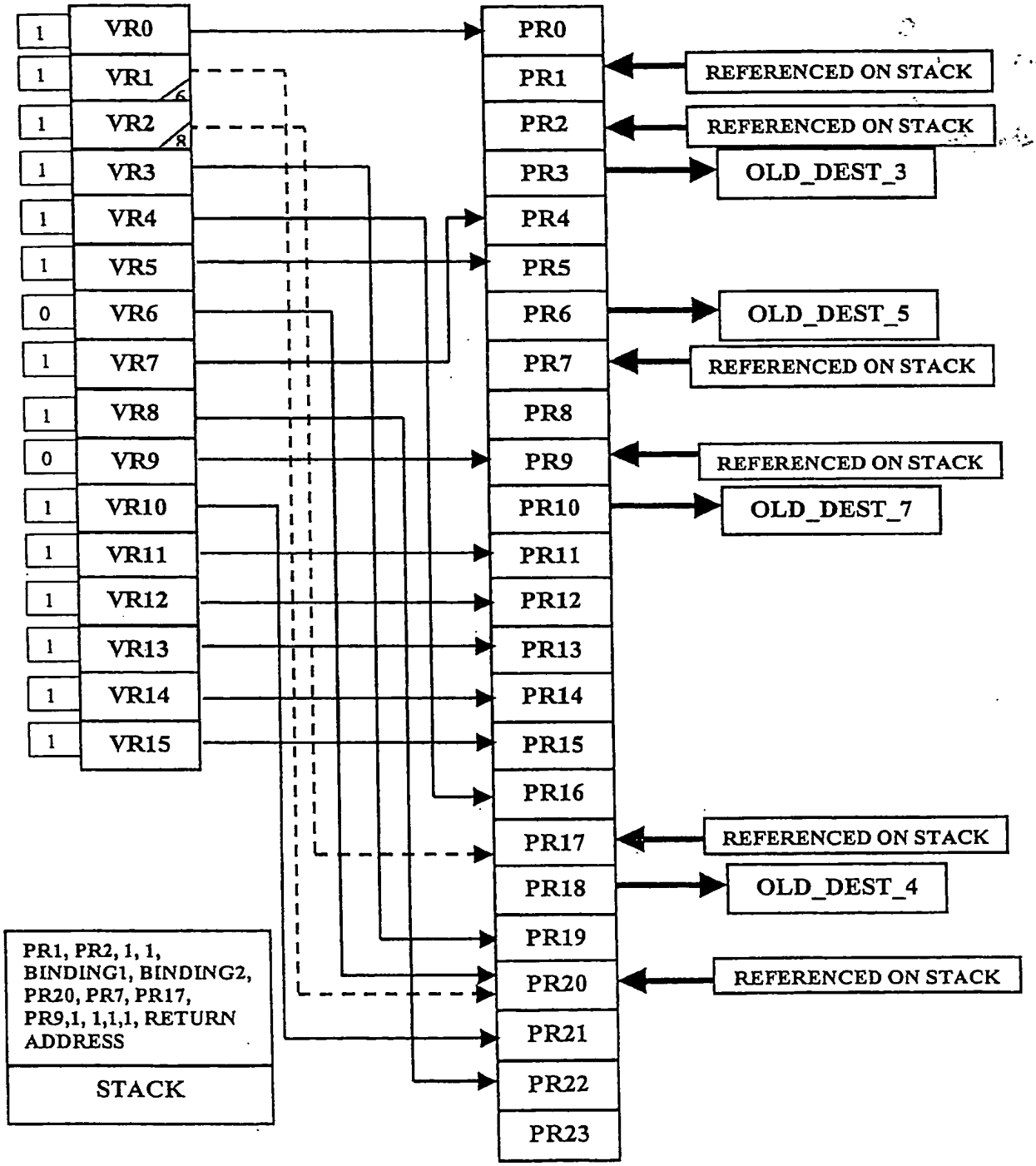
INSTR. 8: SUB VR2, VR3, VR8 **maps to** SUB PR17, PR19, PR22
1 → DIRTY BIT FOR VR8

FIG. 72

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	9	-	WAITING FOR INSTRUCTION 3 TO RETIRE
4	1	-	-	-	INSTRUCTION 1 RETIRED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	7	REFERENCED ON STACK
8	1	-	-	-	INSTRUCTION 2 RETIRED
9	0	1	21	9	REFERENCED ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED,
17	0	1	22	2	INS. 2 EXECUTED, REFERENCED ON STACK
18	0	1	6	-	INS. 3 EXECUTED WAITING FOR 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	0	-	6, 1	WAIT FOR INS. 5 TO EXEC., REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

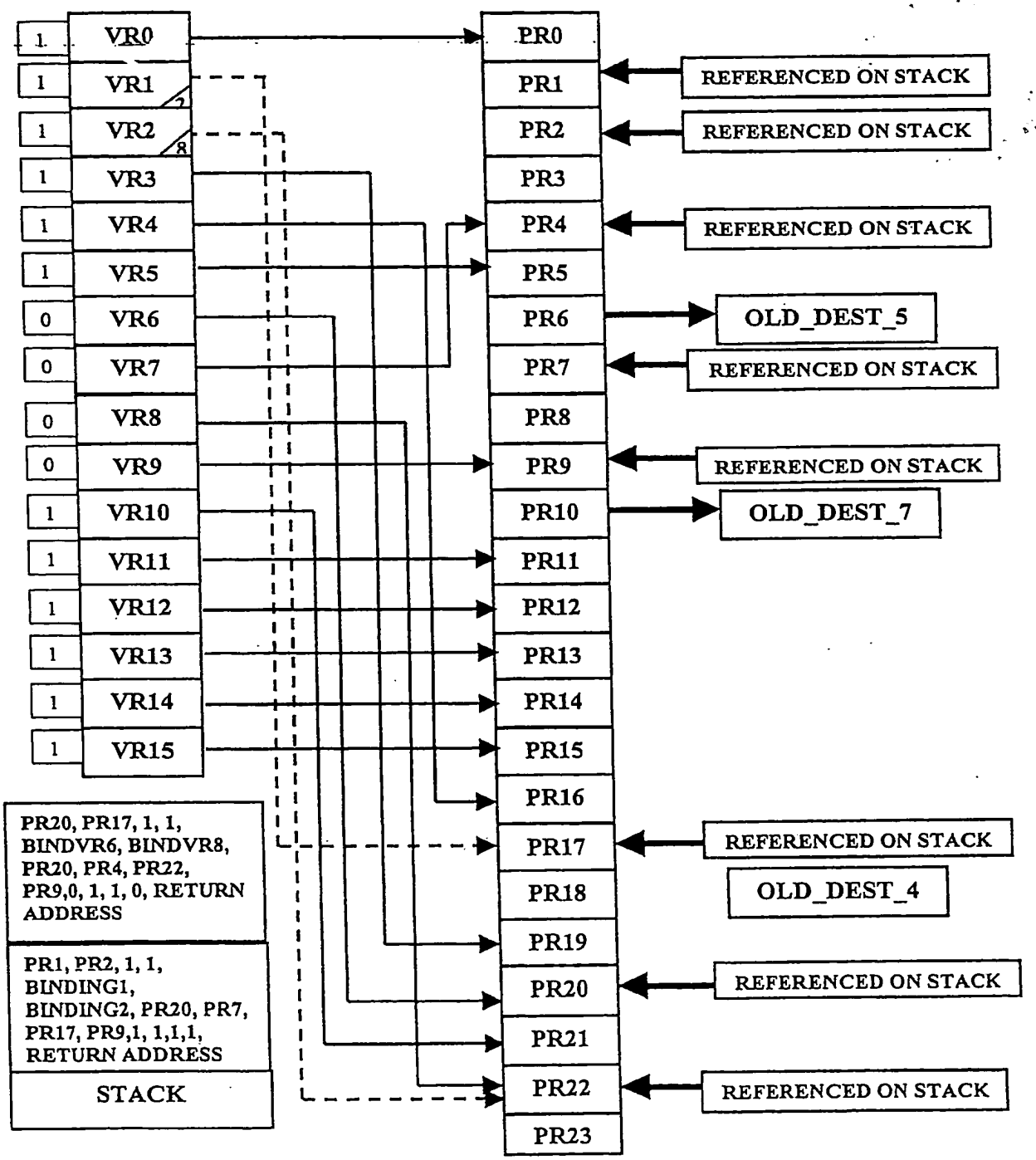
CLOCK 5: DECODE STAGE
INSTRUCTIONS 7 & 8 PHYSICAL REGISTER STATE

FIG. 73



INSTR. 9: MUL VR8, VR1, VR7 maps to MUL PR22, PR20, PR4
1 → DIRTY BIT FOR VR7

FIG. 74



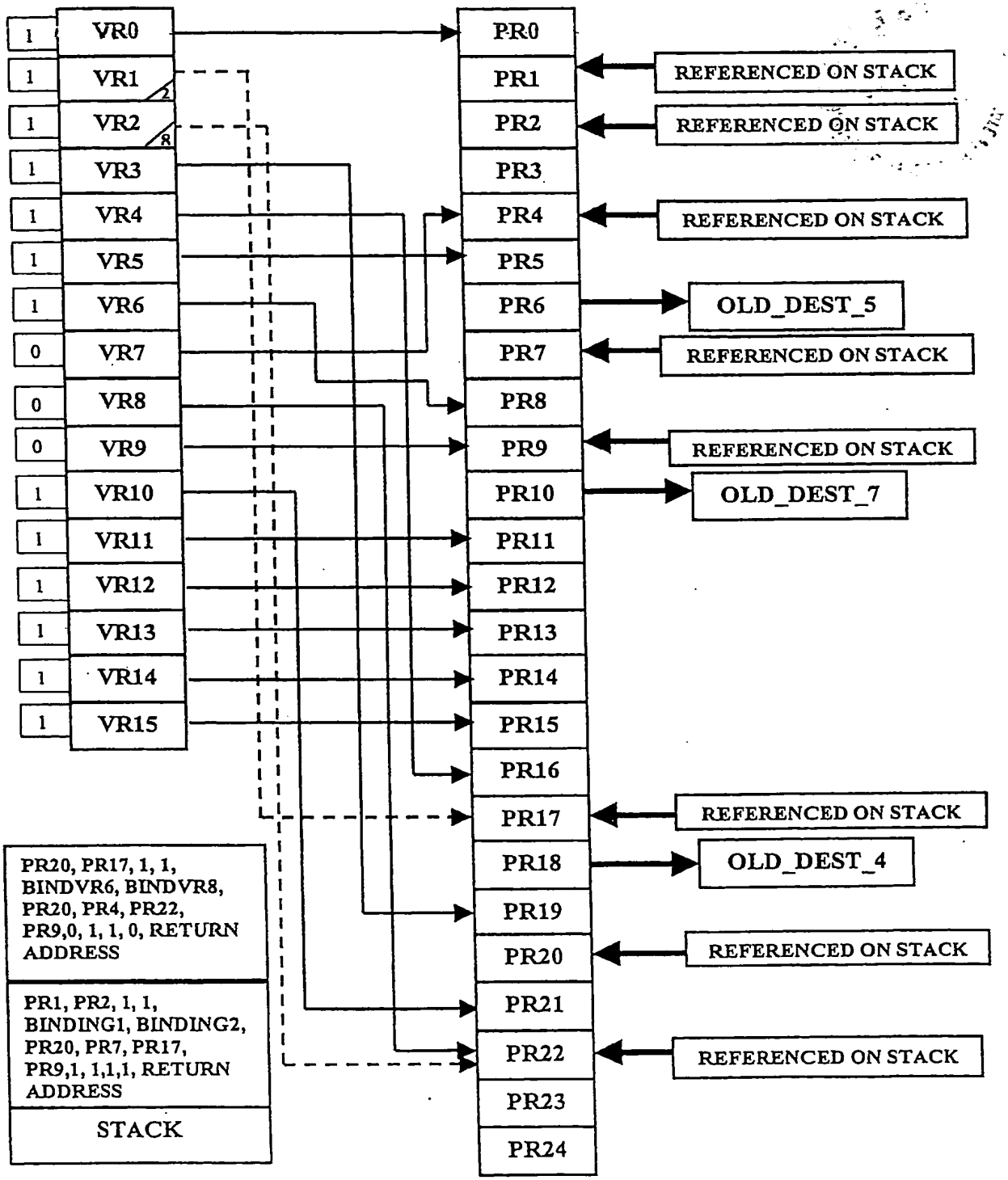
INSTR. 10: CALL B,VR2,VR8 action PUSH PR20, PR17, 1, 1, BINDVR6, BINDVR8, PR20, PR4, PR22, PR9, 0, 1, 1, 0, RETURN ADDRESS; BINDVR2_PR17, BINDVR8_PR22, DIRTY BITS FOR VR2&8 → DIRTY BITS FOR VR1&2, 0000 → DIRTY BITS FOR VR6-9, transfer to B

FIG. 75

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	-	PREVIOUSLY BOUND TO 'BINDING2'
3	1	-	-	-	INSTRUCTION 3 RETIRED
4	0	0	-	7	WAIT FOR INS. 9 TO EXEC., REF'D. ON STACK
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REFERENCE PREVIOUSLY SAVED ON STACK
8	1	-	-	-	UNALLOCATED
9	0	1	21	9	REFERENCE PREVIOUSLY SAVED ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-, 1	INS. 2 EXECUTED, REF'D. ON STACK
18	0	1	6	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	0	-	3	WAITING FOR INSTRUCTION 4 TO EXECUTE
20	0	1	78	6	INS. 5 EXECUTED, REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8, 2	WAIT FOR INS. 8 TO EXEC., REF'D. ON STACK
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

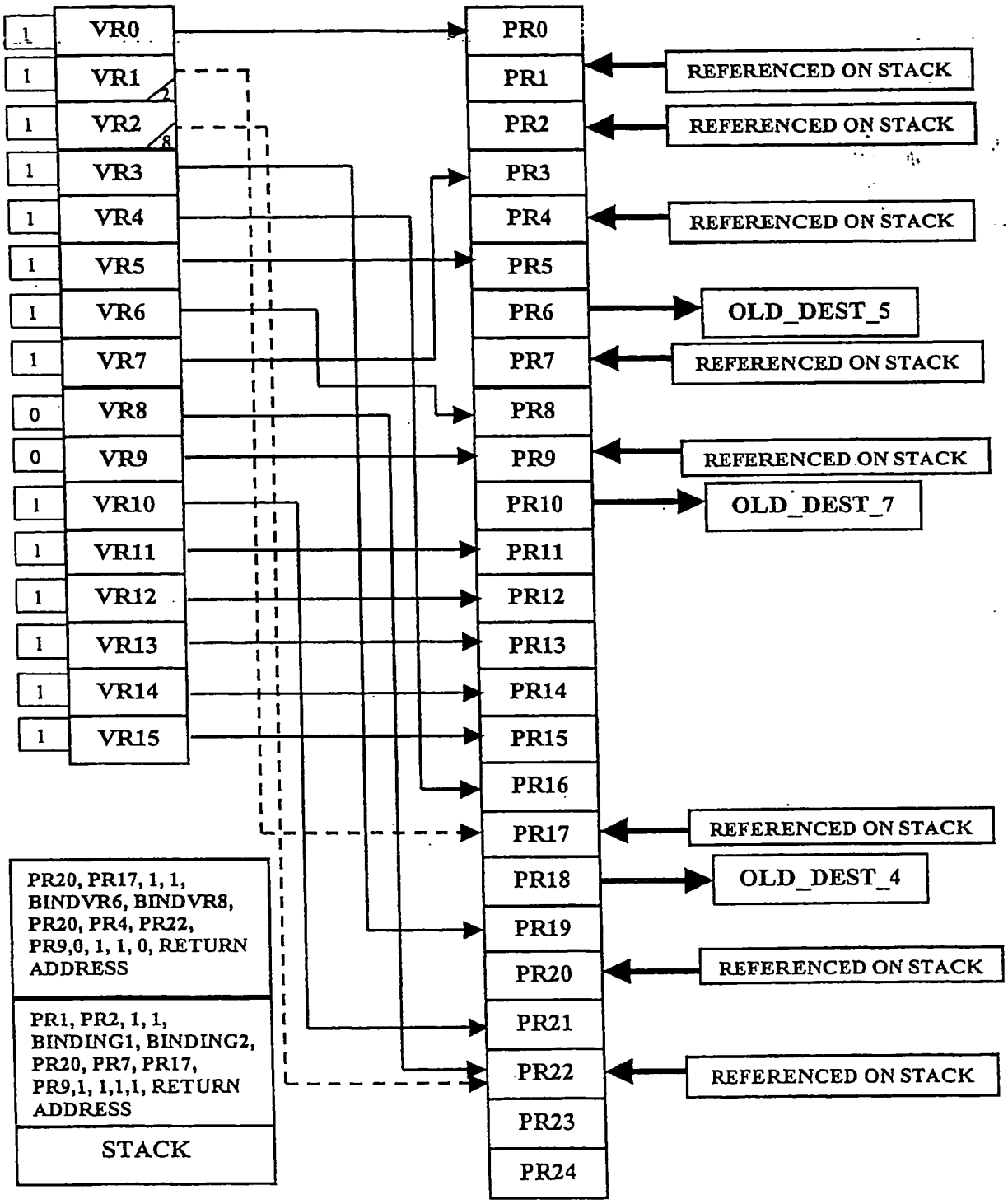
CLOCK 6: DECODE STAGE
INSTRUCTIONS 9 & 10 PHYSICAL REGISTER STATE

FIG. 76



INSTR. 11: ADD VR1, VR2, VR6 maps to ADD PR17, PR22, PR8
1 → DIRTY BIT FOR VR6

FIG. 77



INSTR. 12: ADD VR3, VR7, VR7 maps to ADD PR19, PR4, PR3
1 → DIRTY BIT FOR VR7

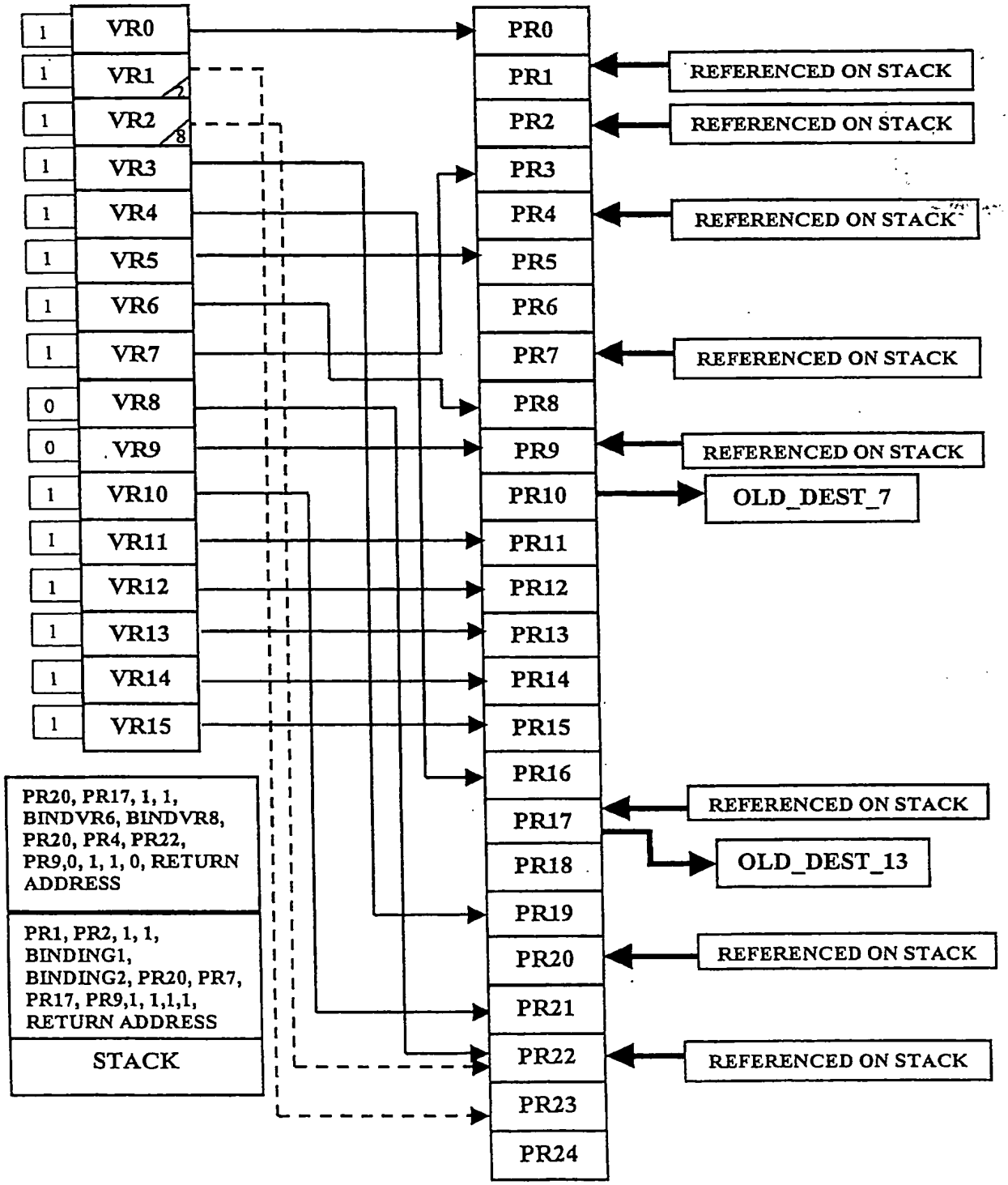
FIG. 78

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	REF'D. ON STACK
2	0	1	7	-	REF'D. ON STACK
3	0	0	-	7	WAITING FOR INSTRUCTION 12 TO EXECUTE
4	0	0	-	-	WAIT FOR INS. 9 TO EXECUTE, REF. SAVED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	15	-	WAITING FOR 5 TO RETIRE
7	0	1	17	-	REF'D. ON STACK
8	0	0	-	6	WAITING FOR INSTRUCTION 11 TO EXECUTE
9	0	1	21	9	REF'D. ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-, 1	INS. 2 EXECUTED, REF'D. ON STACK
18	0	1	6	-	WAITING FOR INSTRUCTION 4 TO RETIRE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8, 2	WAIT FOR INS. 8 TO EXEC., REF'D. ON STACK
23	1	-	-	-	UNALLOCATED
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 7: DECODE STAGE

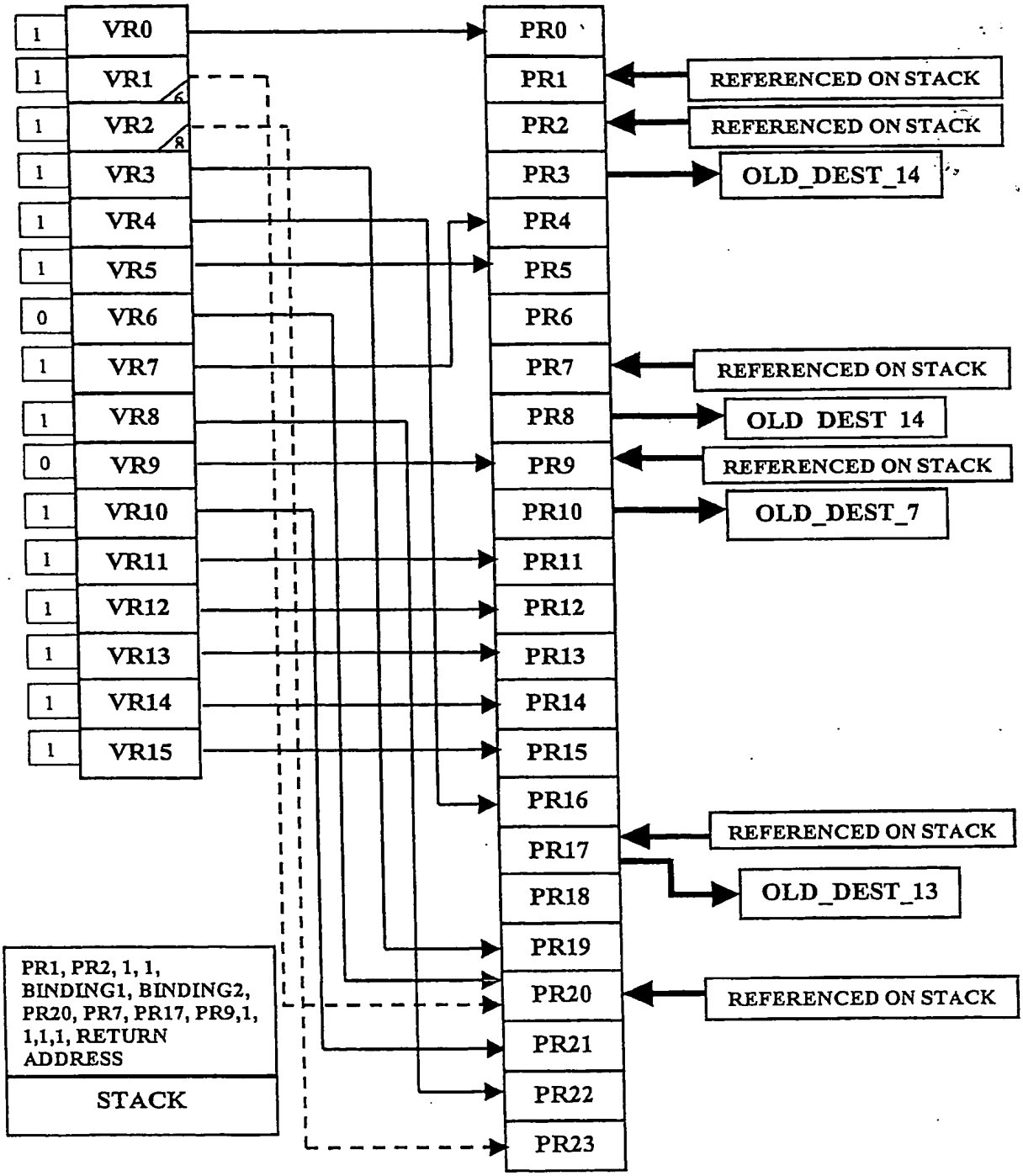
INSTRUCTIONS 11 & 12 PHYSICAL REGISTER STATE

FIG. 79



INSTR. 13: MUL VR6, VR7, VR1 **maps to** MUL PR8, PR3, PR23
PR17 → OLD_DEST_13

FIG. 80



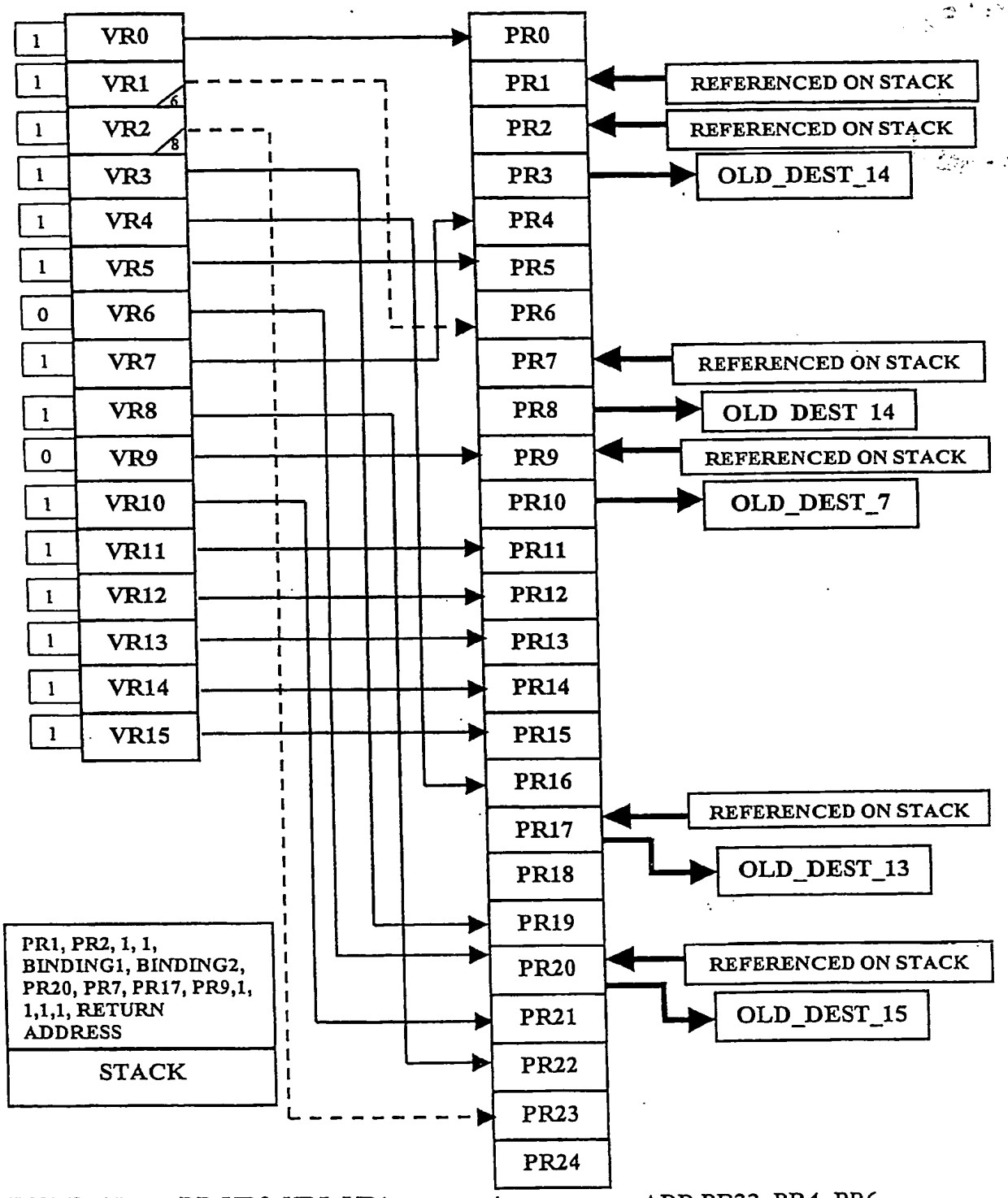
INSTR. 14: RET maps to POP PR20, PR4, PR22, PR9 → VR6-9, 0110 → VR6-9'S DIRTY BITS,
PR20 & PR17 → VR1&2, 11 → DIRTY BITS FOR VR1&2, BINDINGS 6 AND 8 → BINDINGS FOR VR1 AND VR2, RETURN FROM SUBR. B; OLD VABR1's PR23 → VR2 & OLD VABR1's DIRTY BIT → VR2's DIRTY BIT, OLD VABR2's PR22 → VR8 & OLD VABR2's DIRTY BIT → VR8's DIRTY BIT, PR3 & PR8 → OLD_DEST_14

FIG. 81

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	-	REF'D. ON STACK
2	0	1	7	-	REF'D. ON STACK
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	7	WAIT FOR INS. 9 EXEC.
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 5 RETIRED, UNALLOCATED
7	0	1	17	-	REF'D. ON STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	REF'D. ON STACK
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	INS. 2 EXEC, WAIT FOR INS. 13 TO RETIRE
18	1	-	-	-	INSTRUCTION 4 RETIRED, UNALLOCATED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	6, 1	VR6 REF. RESTORED, REF'D. ON STACK
21	0	0	-	10	WAITING FOR INSTRUCTION 7 TO EXECUTE
22	0	0	-	8	WAITING FOR INSTRUCTION 8 TO EXECUTE
23	0	0	-	2	WAITING FOR INSTRUCTION 13 TO EXECUTE
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

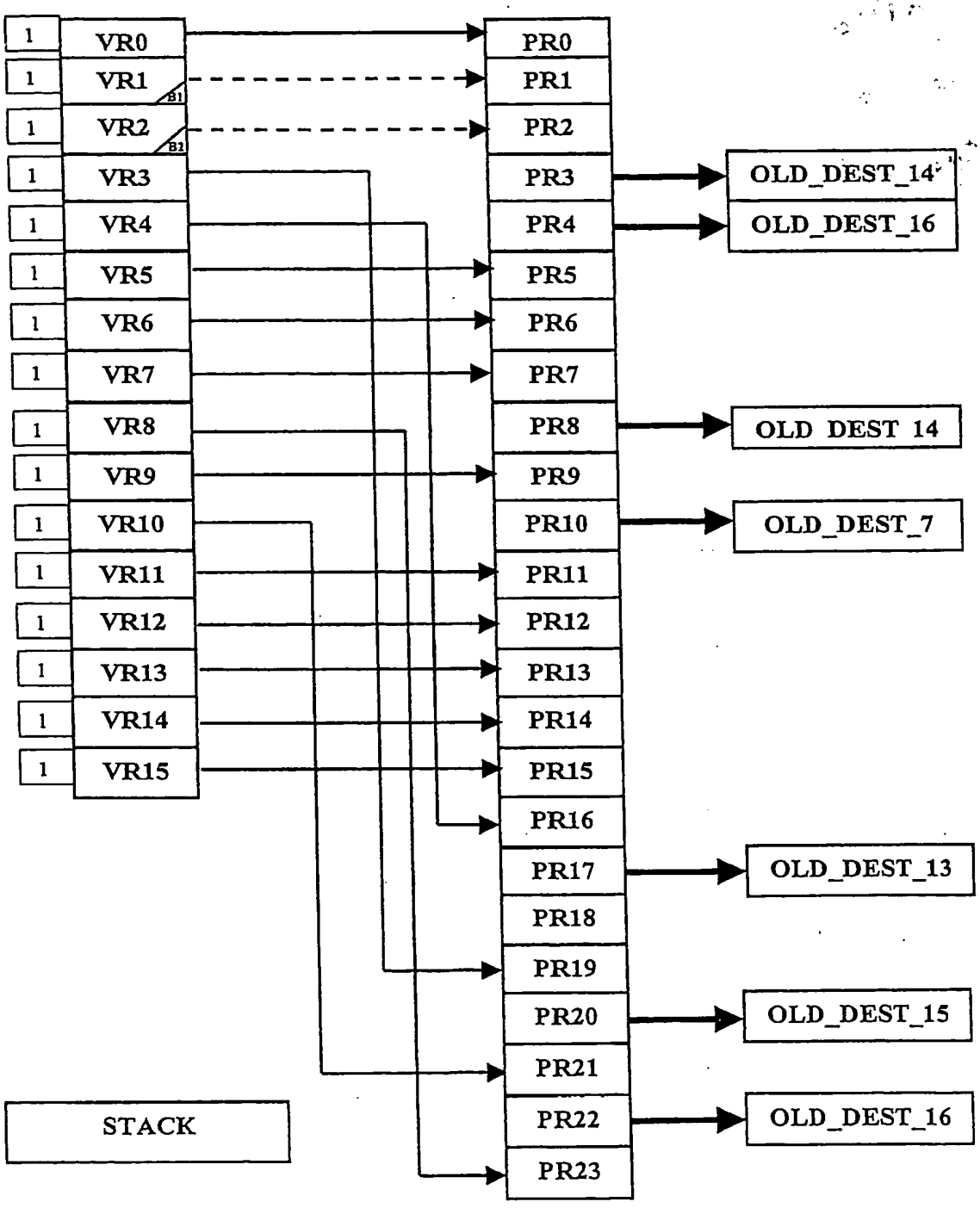
CLOCK 8: DECODE STAGE
INSTRUCTIONS 13 & 14 PHYSICAL REGISTER STATE

FIG. 82



INSTR. 15: ADD VR8, VR7, VR1 maps to ADD PR22, PR4, PR6
PR23 → OLD_DEST_15

FIG. 83



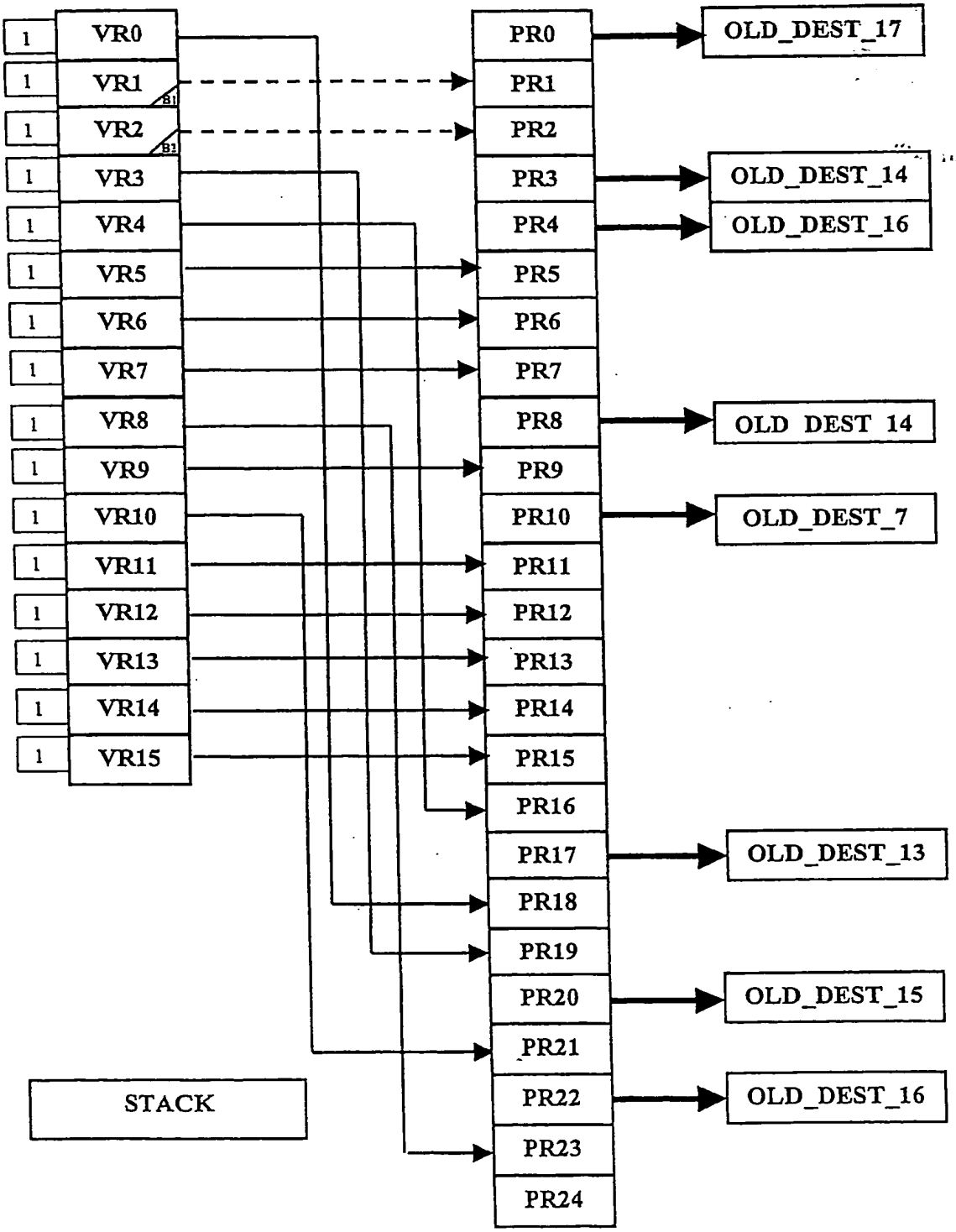
INSTR. 16: RET maps to POP PR20, PR7, PR17, PR9 → VR6-9,
1111 → VR6-9'S DIRTY BITS,
PR1 & PR2 → VR1&2, 11 → DIRTY BITS FOR VR1&2, BINDINGS
B1 AND B2 → BINDINGS FOR VR1 AND VR2, RETURN FROM SUBR. A;
OLD VABR1's PR6 → VR6, OLD VABR2's PR23 → VR8,
OLD VABR1&2 DIRTY BITS → DIRTY BITS FOR VR6 & 8, PR4 & PR22 → OLD_DEST_16

FIG. 84

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	0	EXAMPLE INITIALIZATION
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	0	-	-	WAIT FOR INS. 9 EXEC., INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	6	WAITING FOR INSTRUCTION 15 TO EXECUTE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	0	-	-	WAIT FOR INS. 11 TO EXEC. & 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	0	1	23	-	WAITING FOR INSTRUCTION 7 TO RETIRE
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	1	-	-	-	INSTRUCTION 4 RETIRED, UNALLOCATED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	1	-	-	-	UNALLOCATED
ETC.	1	-	-	-	UNALLOCATED

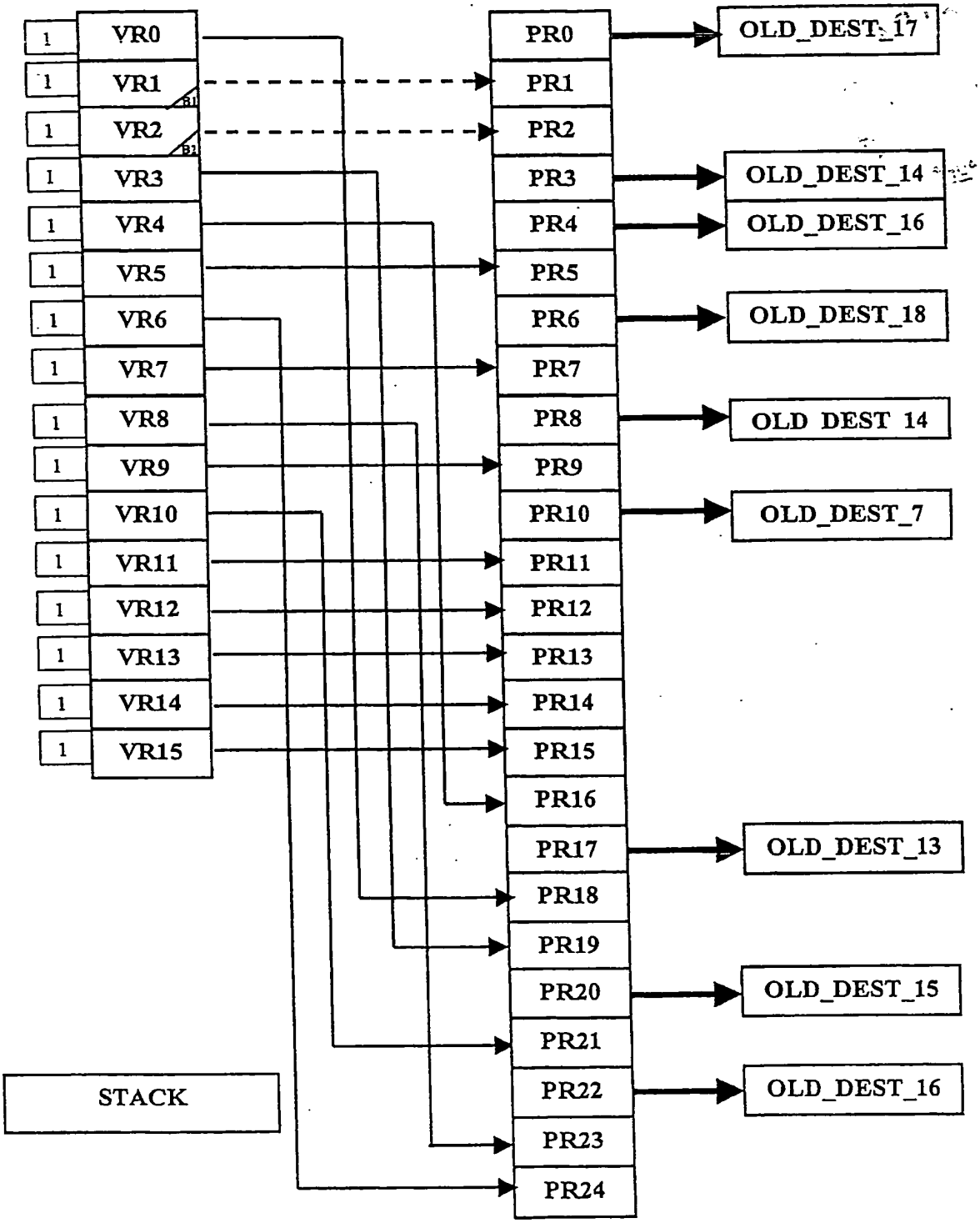
CLOCK 9: DECODE STAGE
INSTRUCTIONS 15 & 16 PHYSICAL REGISTER STATE

FIG. 85



INSTR. 17: ADD VR8, VR0, VR0 maps to ADD PR23, PR0, PR18
PR0 → OLD_DEST_17

FIG. 86



INSTR. 18: ADD VR8, VR6, VR6 maps to ADD PR23, PR6, PR24
PR6 → OLD_DEST_18

FIG. 87

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS.15 TO EXEC. & 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	8	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 10: DECODE STAGE
INSTRUCTIONS 17 & 18 PHYSICAL REGISTER STATE

FIG. 88

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	0	-	-	WAIT FOR INS. 12 TO EXEC. & 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	0	-	-	WAIT FOR INS.15 TO EXEC. & 18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	6	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 11: DECODE STAGE
NO CHANGE IN PHYSICAL REGISTER STATE

FIG. 89

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS.18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	0	-	0	WAIT FOR INSTRUCTION 17 TO EXECUTE
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	0	-	6	WAIT FOR INSTRUCTION 18 TO EXECUTE
ETC.	1	-	-	-	UNALLOCATED

CLOCK 12: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 90

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS.18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	0	-	8	WAIT FOR INS. 13 TO EXEC.
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 13: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 91

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	0	1	3	-	WAITING FOR INS. 17 TO RETIRE
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	0	1	792	-	WAIT FOR INS. 14 TO RETIRE
4	0	1	780	-	WAIT FOR INS. 16 TO RETIRE
5	0	1	13	5	EXAMPLE INITIALIZATION
6	0	1	790	-	WAIT FOR INS.18 TO RETIRE
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	0	1	32	-	WAIT FOR INS. 14 TO RETIRE
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	0	1	22	-	WAITING FOR INS. 13 TO RETIRE
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	0	1	78	-	WAITING FOR INS. 15 TO RETIRE
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	0	1	10	-	WAIT FOR INS. 16 TO RETIRE
23	0	1	25344	8	INSTRUCTION 13 EXECUTED
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 14: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 92

PHYSICAL REGISTER NUMBER	FREE	VALID RESULT	VALUE	VR#	DESCRIPTION
0	1	-	-	-	INS. 17 RETIRED, UNALLOCATED
1	0	1	5	1	PREVIOUSLY BOUND TO 'BINDING1'
2	0	1	7	2	PREVIOUSLY BOUND TO 'BINDING2'
3	1	-	-	-	INSTRUCTION 14 RETIRED, UNALLOCATED
4	1	-	-	-	INSTRUCTION 16 RETIRED, UNALLOCATED
5	0	1	13	5	EXAMPLE INITIALIZATION
6	1	-	-	-	INSTRUCTION 18 RETIRED, UNALLOCATED
7	0	1	17	7	VR7 REFERENCE RESTORED FROM STACK
8	1	-	-	-	INSTRUCTION. 14 RETIRED, UNALLOCATED
9	0	1	21	9	EXAMPLE INITIALIZATION
10	1	-	-	-	INSTRUCTION 7 RETIRED, UNALLOCATED
11	0	1	25	11	EXAMPLE INITIALIZATION
12	0	1	27	12	EXAMPLE INITIALIZATION
13	0	1	29	13	EXAMPLE INITIALIZATION
14	0	1	31	14	EXAMPLE INITIALIZATION
15	0	1	33	15	EXAMPLE INITIALIZATION
16	0	1	6	4	INSTRUCTION 1 EXECUTED
17	1	-	-	-	INS. 13 RETIRED, UNALLOCATED
18	0	1	25347	0	INSTRUCTION 17 EXECUTED
19	0	1	12	3	INSTRUCTION 4 EXECUTED
20	1	-	-	-	INS. 15 RETIRED, UNALLOCATED
21	0	1	90	10	INSTRUCTION 7 EXECUTED
22	1	-	-	-	INSTRUCTION 16 RETIRED, UNALLOCATED
23	0	1	25344	8	INSTRUCTION 13 EXECUTED
24	0	1	26134	6	INSTRUCTION 18 EXECUTED
ETC.	1	-	-	-	UNALLOCATED

CLOCK 15: DECODE STAGE
PHYSICAL REGISTER STATE

FIG. 93